DETERMINATION OF ERRORS IN A SERIES TRANSFORMER

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DETERMINATION OF ERRORS

IN A

SERIES TRANSFORMER

A THESIS

PRESENTED BY

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It was intended at the outset to run a test on several transformers of various types, but it was later found that the project took a great deal more time than was anticipated. For this reason a full set of data was obtained on only one transformer.

The calculated data and the curves shown in this thesis are those for a General Electric Series Transformer, Type C, Form D, #30266, built for 15500 volts on the main. Ratio 20 to 1. Full load 75 amperes, thirty minute load 100 amperes.

Further data on a different transformer is included in this thesis but it is not worked up.

A series transformer is a device commonly used in high potential power lines for supplying current to an ammeter or the series coil of a wattmeter.

It being undesirable to bring the high potential feeders directly to the switch board on account of the danger thus involved the series transformer was developed.

It occupies the same place in alternating current work as does the shunt in direct current lines, namely; that of supplying a definite ratio of the total current flowing through the lines to instruments whose scales are so calibrated that the total amount of current flowing is read, instead, of just that portion which flows through them.

The transformer is essentially a few turns of heavy wire, wound on a porcelain core, which are connected in series with the line, in which the current is to be measured. The secondary consists of a large number of smaller turns wound around the primary winding. The measuring instruments connect directly to these secondary terminals.

If the transformer is designed for some particular instrument with its known length of leads from the transformer to the switch board it can be so constructed that the percent error on all loads is very small.

As the above is very seldom the case, since certain types of transformers are used on different types of instruments and different lengths of leads, an error is introduced which depends upon the nature of the secondary circuit and the size of the load.

The commonly recognized error of these transformers is that of variation of the ratio of transformation. Another source of

error, which is seldom mentioned is that of the phase relations of the currents in the primary and secondary of the transformer. The error caused by this latter is practically neglegible at unity power factor but rapidly increases for lower power factors.

In a transformer the primary and secondary currents are nearly always assumed to be 180° apart. This is very seldom the case but does not make much difference in general cases.

In a series transformer where its sole function is to supply current for power measuring instruments an error, however small, causes a loss where large amounts of power are measured.

The current in the secondary of a transformer of the series type instead of being just 180° behind the current in the primary, lags it (the 180° position) by a small angle which will be called alpha (a) in this work.

The object of the following work is to find the value of that angle and also the ratio of transformation under different characters of secondary circuits for loads varying from light loads to over loads. The value of the ratio of transformation is a very easy quantity to obtain since it is just the ratio of the primary to the secondary current and these values can be obtained very ~~rapidly~~ readily. The method of obtaining the phase angle was a harder matter as the literature on that subject was of very meagre nature. The only reference found, was that in the transactions of the American Institute of Electrical Engineers of 1906.

An oscillograph was thought of, but as the angle to be measured ~~is~~ was so small compared to the scale of the oscillograms which could be obtained, that another method was thought more applicable.

The method used is a rather simple one and consists of two sensitive dynamometers, the stationary coils of which are connected in parallel, one of them first going through an ammeter.

These coils are then connected through a bank of lamps to the secondary of a three phase, squirrle cage, induction motor, the secondaries of each phase being open and connected to sliprings. By supplying current to the primary of the induction motor a revolving field is set up and by moving the rotor the desired amount and clamping it in place, a current which varies from the primary current by an amount equal to from zero to 120,° depending upon the position of rotor, can be obtained.

The moving coil of one dynamometer was connected to a shunt in the primary circuit. The moving coil of the other dynamometer was connected through an ammeter to the secondary of the transformer to be tested. A double pole switch was placed in each circuit so that the instruments could be cut out when desired. A single pole switch was placed across the secondary terminals of the transformer so it could be short-ed when the other switches were open. This was necessary because if it was left open a high e.m.f. would be set up in the secondary due to the primary current. This e.m.f. would be liable to puncture the insulation.

As a large current was needed the most convenient way of obtaining it was decided to be that, of using a high current transformer, which had a ratio of eleven , twenty-two, forty-four, depending upon the way of connecting. A current as high as three thousand amperes could be obtained with this if desired but as only one hundred was needed it was connected up with the twenty-two ratio and by varying the current in the primary by means of a lamp rack and some carbon rheostats the value of the secondary current of this transformer could be changed at will.

The secondary of this transformer was connected directly through the primary of the series transformer and the shunt spoken of before.

A frequency meter was also supplied, as were double-throw switches for balancing the dynamometers against each other if desired. The scheme of wiring can easily be seen from the accompaning blue print.

The method of working the apparatus is as follows: Current is sent through both coils of the dynamometer by manipulation of the lamp racks. Then by moving the handle connected to the rotor of the induction motor the phase relation of the current in the stationary coils is adjusted to 90° difference from that in the moving coil of the dynamometer connected onto the shunt. The current in the coil connected to the shunt is in phase with the primary current of the transformer. A 90° difference in phase relation of the currents will cause the dynamometer connected to the shunt to read zero.

If the current in the secondary of the transformer is just 180° out of phase with the primary current the dynamometer across it will read zero. If it does not read zero, the deflection is noted and the values of the currents in each of its coils are taken. The deflection obtained is proportional to the sine of the angle of lag since the deflection of the dynamometer is equal to the products of the currents through each coil times the cosine of the angle between them or $D=KI_1I_2 \cos \theta^\circ$. By adjusting the dynamometer across the shunt for zero deflection θ° becomes 90° so the angle between the currents in the second dynamometer is $(90^\circ-a)$. Therefor $D=KI_1I_2 \cos(90^\circ-a)=KI_1I_2 \sin(a)$.

The dynamometer was calibrated as an ammeter on direct current so the value of the cosine ~~is~~ was one and as the two coils were in series $I_1 = I_2$ then $D = KI_1^2$. This enabled one to determine the value of K for different deflections and a curve was plotted so these values could be taken off. The ammeters were calibrated and curves plotted for them as was also done for all the instruments used.

When the experiment first started an ammeter was placed in the circuit of the moving coil connected across the shunt so by ratio of the resistance of these two circuits and the reading of the ammeter in the secondary of the transformer the ratio of transformation could be obtained directly. This cut down the sensibility of the dynamometer so much that it was taken out and the ratio obtained separately by means of a hot wire ammeter connected across the shunt. By plotting a curve for these ratio readings the value of the primary current corresponding to the secondary current taken during the phase angle readings could be obtained and the ratio obtained by their division.

In order to obtain the impedance of the secondary circuit a special instrument had to be used because there was no low reading alternating current voltmeter obtainable. In order to obtain an instrument, a Whitney hot wire ammeter which is commonly used across a shunt was calibrated as a voltmeter as follows:
It was placed across the shunt and readings taken of current flowing through the shunt and the reading of ammeter. A milli-voltmeter was then placed across the shunt and readings of it taken corresponding to line current. By plotting a curve against ammeter readings and milli-volt readings the calibration of the ammeter as a voltmeter was obtained.

In obtaining the impedance drops, the drop had to be taken over the ammeter which was in the circuit or the true value of current flowing through the circuit could not be obtained. As this could not always be done it was necessary to calibrate the instrument as an ammeter without its shunt. Then by subtracting the current flowing through it from the ammeter reading the true value of the current in the circuit was obtained and then $Z = \frac{E}{I}$ where E is the voltage as indicated by the instrument and I is the corrected current. This was necessary because the instrument had such a low resistance that more current flowed through it, than did through the circuit to be measured. The resistance of the circuit was obtained by the fall of potential method using a calibrated ammeter and voltmeter.

The symbols and letters used in this work have the following meanings:

R_s :	Resistance of secondary circuit.
L :	Reactance of secondary circuit.
I_{ph} :	Current in phase-shifter.
I_s :	Current in transformer secondary.
I_p :	Current in transformer primary.
Defl. :	Dynamometer deflection.
K :	Dynamometer constant.
R :	Ratio of primary current to secondary current.
$'$:	Corrected values of above symbols.

The circuits used are composed of the following; as taken from the data sheets on resistance and impedance.

No.	Character.
1	(a)
3	(b) + (c)
4	(a) + (c)
5	(c) + (h)
6	(c) + (i)
7	(e)
8	(f)
10	(g)
11	(k) + (c)

The nature of the secondary circuits used are as follows:

No.	R	L
4	.35460	.[illegible]
5	"	.0054000
11	"	.009[illegible]60
13	"	.01[illegible]0000
6	"	.01[illegible]000
1	.09060	.0003400
7	.15[illegible]70	"
1[illegible]	.21[illegible]00	"
8	.[illegible]920	"
10	.25900	"
3	.[illegible]060	.[illegible]010740

Resistance.

(a)

I	E	#I	#E	R
1	0.270	0.99	0.260	0.263
2	0.530	1.98	0.520	0.263
3	0.795	2.96	0.790	0.267
4	1.050	3.89	1.035	0.266
5	1.300	4.86	1.270	0.262

(b)

I	E	#I	#E	R
1	0.135	0.99	0.130	0.1315
2	0.265	1.98	0.265	0.1337
3	0.392	2.96	0.380	0.1285
4	0.520	3.89	0.510	0.1278
5	0.640	4.86	0.625	0.1286

(c)

I	E	#I	#E	R
1	0.090	0.99	0.090	0.0910
2	0.180	1.98	0.175	0.0885
3	0.275	2.96	0.270	0.0913
4	0.368	3.89	0.360	0.0903
5	0.455	4.86	0.445	0.0917

(d)

I	E	#I	#E	R
1	0.105	0.99	0.105	0.1062
2	0.210	1.98	0.205	0.1035
3	0.230	2.96	0.310	0.1047
4	0.425	3.89	0.415	0.1040
5	0.525	4.86	0.510	0.1050

(e)

I	E	#I	#E	R
1	0.238	0.99	0.237	0.2495
2	0.465	1.98	0.455	0.2300
3	0.690	2.96	0.670	0.2265
4	0.920	3.89	0.900	0.2310
5	1.135	4.86	1.100	0.2290

(f)

I	E	#I	#E	R
1	0.132	0.99	0.130	0.1315
2	0.258	1.98	0.250	0.1265
3	0.392	2.96	0.380	0.1285
4	0.513	3.89	0.500	0.1265
5	0.640	4.86	0.625	0.1285

(g)

I	E	#I	#E	R
1	0.262	0.99	0.26	0.263
2	0.520	1.98	0.51	0.257
3	0.775	2.96	0.76	0.257
4	1.035	3.89	1.01	0.260
5	1.285	4.86	1.25	0.257

Impedance.

(a)

I_2	E_H	Alt.	# I_2	I_{HW}	I_c	E	Z
1.423	40.0	50/50	1.430	1.245	0.185	0.117	0.633
2.152	60.0	"	2.165	1.860	0.305	0.171	0.562
2.808	80.0	"	2.830	2.440	0.390	0.229	0.588
3.150	90.0	"	3.185	2.730	0.455	0.257	0.565
3.478	100.0	"	3.525	3.000	0.525	0.286	0.545

(b)

I_2	E_H	Alt.	# I_2	I_{HW}	I_c	E	Z
1.890	40.0	50.50	1.715	1.345	0.370	0.117	0.1750
2.800	60.0	" "	2.825	1.860	0.965	0.171	0.177[illegible]
3.738	80.0	"	3.785	2.440	1.345	0.229	0.1700
4.600	100.0	"	4.65	3.000	1.650	0.286	0.1735

(c)

I_2	E_H	Alt.	# I_2	$I_{H.W}$	I_c	E	Z
0.550	20.0	50.50	0.530	0	0.530	0.06[illegible]	0.121
1.083	40.0	"	1.085	0	1.085	0.117	0.108
1.600	60.0	"	1.600	0	1.600	0.171	0.107
2.148	80.0	"	2.165	0	2.165	0.229	0.106
2.373	90.0	"	2.405	0	2.405	0.257	0.1068
2.650	100.0	"	2.675	0	2.675	0.286	0.107
1.075	40.0	51.60	1.075	0	1.075	0.117	0.1088
1.600	60.0	"	1.610	0	1.610	0.171	0.106
2.185	80.0	"	2.225	0	2.225	0.229	0.103
2.435	90.0	"	2.470	0	2.470	0.257	0.104
2.718	100.0	"	2.750	0	2.750	0.28[illegible]	0.104

Impedance.

(d)

I_2	E_H	Alt.	# I_2	I_{HW}	I_c	E	Z
0.875	40.0	51.0	0.875	0	0.875	0.117	0.1340
1.335	60.0	"	1.339	0	1.339	0.171	0.1275
1.818	80.0	"	1.835	0	1.835	0.229	0.1250
2.028	90.0	"	2.040	0	2.040	0.257	0.1400
2.26	100.0	"	2.290	0	2.290	0.286	0.1250

(h)

I_2	E_H	Alt.	# I_2	$I_{H.W}$	I_c	E	Z
1.345	40.0	50.50	1.345	1.245	0.100	0.117	1.170
1.960	60.0	"	1.980	1.860	0.120	0.171	1.425
2.550	80.0	"	2.556	2.440	0.110	0.229	2.80
3.165	100.0	"	3.200	3.000	0.200	0.286	1.430

(i)

I_2	E_H	Alt.	# I_2	I_{HW}	I_c	E	Z
0.790	24.0	50.25	0.780	0.760	0.02	0.076	3.80
1.275	40.0	"	1.275	1.245	0.030	0.117	3.90
1.870	60.0	"	1.900	1.860	0.04	0.171	4.50
2.445	80.0	"	2.460	2.440	0.020	0.229	1.14
3.030	100.0	"	3.060	3.000	0.060	0.28[illegible]	4.75

(k)

I_2	E_H	Alt.	# I_2	$I_{H.W}$	I_c	E	Z
1.380	40.0	50.50	1.370	1.245	0.115	0.117	1.017
2.050	60.0	"	2.060	1.860	0.200	0.171	0.850
2.690	80.0	"	2.710	2.440	0.270	0.229	0.850
3.310	100.0	"	3.350	3.000	0.350	0.286	0.820

Ratio Readings.

I_H	I_2	I_p	I_s	I_H	I_2	I_p	I_s
8.0	0.50	11.5	0.50	12.0	0.60	15.5	0.60
19.9	1.13	22.8	1.15	22.0	1.21	24.5	1.21
31.0	1.63	32.5	1.65	32.0	1.62	33.5	1.64
40.0	2.08	41.0	2.10	40.0	2.08	41.0	2.10
50.0	2.56	51.0	2.56	50.0	2.55	51.0	2.55
60.0	3.07	61.2	3.11	60.0	3.09	61.2	3.13
70.0	3.63	71.8	3.68	70.0	3.68	71.8	3.73
80.0	4.10	82.0	4.15	80.0	4.14	82.0	4.20
90.0	4.60	91.3	4.65	90.0	4.65	91.3	4.70
96.8	4.98	97.8	4.98	95.2	4.97	96.5	4.98

Circuit #4

I_H	I_2	I_p	I_s
10.0	0.58	13.5	0.58
22.0	1.20	24.5	1.21
30.0	1.55	31.7	1.56
40.0	2.08	41.0	2.09
50.0	2.55	51.0	2.61
60.0	3.09	61.2	3.13
70.0	3.65	71.8	3.70
80.0	4.11	82.0	4.16
90.0	4.63	91.3	4.68
95.0	4.95	96.2	4.97

Ratio Readings.

Circuit #5

I_H	I_2	I_p	I_s
10.0	0.61	13.5	0.61
22.0	1.24	24.5	1.24
40.0	2.12	41.0	2.12
60.0	3.10	61.2	3.13
80.0	4.16	82.0	4.22
93.0	4.88	94.2	4.92

Circuit #6

I_H	I_2	I_p	I_s
10.0	0.59	13.5	0.59
22.0	1.23	24.5	1.22
40.0	2.10	41.0	2.10
60.0	3.08	61.2	3.11
80.0	4.11	82.0	4.16
92.0	4.74	93.3	4.78

Circuit #7

I_H	I_2	I_p	I_s
10.0	0.65	13.5	0.65
22.0	1.23	24.5	1.23
40.0	2.12	41.0	2.12
60.0	3.13	61.2	3.13
80.0	4.18	82.0	4.25
95.0	5.0	96.2	5.01

Circuit #8

I_H	I_2	I_p	I_s
10.0	0.60	13.5	0.60
22.0	1.25	24.5	1.23
40.0	2.09	41.0	2.10
60.0	3.09	61.2	3.12
80.0	4.17	82.0	4.23
95.0	4.96	96.2	4.98

Circuit #10

I_H	I_2	I_p	I_s
10.0	0.60	13.5	0.60
20.0	1.09	22.8	1.09
40.0	2.08	41.0	2.10
60.0	3.05	61.2	3.09
80.0	4.05	82.0	4.10
90.0	4.64	91.3	4.69
95.0	4.95	96.2	4.97

Circuit #11

I_H	I_2	I_p	I_s
20.0	1.08	22.8	1.08
40.0	2.08	41.0	2.10
60.0	3.09	61.2	3.13
80.0	4.14	82.0	4.17
90.0	4.64	91.3	4.69
95.0	4.95	96.2	4.97

Ratio Readings.

Circuit #12.

I_H	I_2	I_p	I_s
10.0	0.[illegible]00	1[illegible].50	0.[illegible]00
20.0	1.140	[illegible]2.80	1.1[illegible]5
[illegible].0	2.100	41.80	2.100
[illegible]0.0	3.06[illegible]	61.20	3.0[illegible]
80.0	4.070	82.00	4.120
95.0	4.900	95.[illegible]0	4.920

Circuit #14.

I_H	I_2	I_p	I_s
10.0	[illegible].600	1[illegible].[illegible]0	0.700
[illegible].0	1.2[illegible]0	[illegible].50	1.[illegible]10
40.0	[illegible].050	41.00	2.050
60.0	[illegible].055	[illegible]1.20	3.080
80.0	4.060	82.00	4.110
95.[illegible]	4.910	9[illegible].80	4.940

Resistance #1 .

I	E	#I	#E	R
1	0.[illegible]2	0.[illegible]9	0.[illegible]10	.1[illegible]
2	0.450	1.98	0.4[illegible]0	.120
3	0.655	[illegible].96	0.6[illegible]5	.[illegible]110
4	0.847	3.8[illegible]	0.830	.130
5	1.055	4.96	1.[illegible]30	.[illegible]120

Impedance #14.

I_2	E_H	Alt.	# I_2	I_{HW}	I_c	E	Z
0.[illegible]	[illegible]4.0	50.50	0.790	0.760	0.030	0.0[illegible]	[illegible].53
1.[illegible]83	40.0	50.50	1.280	1.[illegible]40	.041	.117	[illegible].97
2.500	80.0	50.50	2.520	2.440	0.080	0.[illegible]9	2.[illegible]
3.100	100.0	50.50	3.1[illegible]	3.000	0.125	0.2[illegible]	2.2[illegible]

Circuit #1

R_s=.0906 L=.00[illegible]540

I_{ph}	I_2	Defl.	K	$I\#_{ph}$	$\#I_s$	Sin.a	I_p	R	Alpha ° '
4.49	0.20	4.0	76.10	4.55	0.180	.0643	1.8	10.00	3 41.2
4.54	0.30	7.5	79.00	4.60	0.288	.0717	6.0	20.83	4 06.7
4.48	0.62	12.0	80.80	4.54	0.5[illegible]5	.06[illegible]3	11.2	21.32	3 34.3
4.46	0.85	14.0	81.40	4.52	0.850	.0448	18.0	21.18	2 34.0
4.44	1.0	16.0	81.80	4.50	1.000	.0435	21.1	21.10	2 29.5
4.47	1.18	18.5	82.00	4.53	1.190	.0418	25.1	21.10	2 23.7
4.42	1.33	21.0	82.70	4.485	1.338	.0422	28.2	21.08	2 25.0
4.41	1.47	23.2	83.00	4.48	1.476	.0422	31.0	21.00	2 25.0
4.44	1.63	25.0	83.20	4.50	1.630	.0405	34.4	20.84	2 19.3
4.53	1.72	27.5	83.50	4.58	1.738	.0413	36.0	20.70	2 22.0
4.43	1.83	29.0	83.65	4.49	1.850	.0417	38.1	20.58	2 23.3
4.49	1.94	30.0	83.75	4.55	1.960	.0402	40.1	20.45	2 18.25
4.48	2.05	33.0	84.00	4.54	2.050	00422	42.1	20.50	2 25.0
4.38	2.22	33.5	84.05	4.45	2.250	.0399	46.0	20.45	2 17.2
4.48	2.32	37.5	84.35	4.54	2.350	.0417	48.0	20.41	2 23.3
4.41	2.50	39.3	84.45	4.470	2.550	.0412	51.4	20.30	2 21.6
4.43	2.73	42.0	84.50	4.49	2.765	.0400	55.6	20.10	2 17.5
4.40	2.98	45.0	84.55	4.4[illegible]	3.015	.0396	60.6	20.07	2 16.2
4.42	3.22	49.5	84.[illegible]5	4.48	3.26[illegible]	.0400	65.4	20.04	2 17.5
4.43	3.55	55.5	84.50	4.49	3.600	.0392	72.0	20.[illegible]0	2 14.8
4.41	3.87	56.0	84.45	4:4[illegible]	3.925	.0378	78.0	19.89	2 10.0
4.41	4.23	61.5	84.35	4.48	4.285	.0379	85.0	19.81	2 10.3
4.46	4.57	65.4	84.30	4.52	4.[illegible]50	.0371	91.3	19.[illegible]0	2 07.2

Circuit #3

R_g = . 206 [illegible] = .[illegible]10[illegible]

. I_{ph}	I_L	Defl.	K	# I_{ph}	# I_L	Sin.a	I_p	[illegible]	Angle a (° ′)
4.45	[illegible].20	6.0	78.20	4.50	0.180	.094[illegible]	[illegible]	12.50	5 25.[illegible]
4.44	0.40	11.0	80.40	4.50	0.390	.0779	9.00	23.10	4 [illegible].0
4.45	0.63	14.0	81.[illegible]	4.51	0.65	.061[illegible]	13.6	2[illegible].10	3 30.2
4.46	0.97	17.0	81.90	4.51	0.870	.0[illegible]0	1[illegible].0	21.85	3 0[illegible].3
4.46	1.11	19.8	82.40	4.51	1.11[illegible]	.0478	[illegible]4.0	21.55	2 [illegible]
4.44	1.28	21.5	[illegible].70	4.50	1.285	.0450	27.[illegible]	21.15	2 [illegible]
4.46	1.50	25.0	8[illegible].15	[illegible].51	1.511	.0443	31.[illegible]	20.90	2 32.4
4.40	1.67	27.0	83.40	4.51	1.690	.0425	35.2	20.62	2 26.1
4.47	1.92	30.9	87.85	4.52	2.000	.0406	40.9	20.45	2 19.6
4.48	2.45	35.5	84.77	4.55	2.450	.0379	49.5	20.30	2 10.3
4.47	2.65	39.[illegible]	84.40	4.52	2.675	.0364	55.8	20.10	2 12.0
4.49	3.03	42.[illegible]	84.30	4.54	3.07[illegible]	.05[illegible]0	61.1	19.85	2 03.[illegible]
4.48	3.57	48.0	84.60	4.53	3.[illegible]0	.0[illegible]	71.[illegible]	19.70	1 59.0
4.31	3.90	50.0	84.58	4.39	3.960	.0[illegible]39	77.5	19.55	1 [illegible]
4.37	4.30	5[illegible].0	84.60	4.43	4.3[illegible]0	.0337	84.5	19.40	1 5[illegible].0
4.45	4.[illegible]	57.0	84.[illegible]	4.50	4.[illegible]	.0320	90.3	1[illegible].37	1 30.0
4.40	5.00	6[illegible].3	84.52	4.50	[illegible].100	.0334	[illegible].5	1[illegible].30	1 34.[illegible]

Circuit #4.

R_{ag}=.3[illegible]4[illegible] L=.003[illegible]8[illegible]

I_{ph}	I_2	Defl.	E	"I_{ph}	"I_s	Mi[illegible].a	I_p	T	al[illegible] ° '
4.60	0.30	9.0	79.75	4.63	0.288	.0343	6.0	20.84	4 50.2
4.62	0.75	14.8	81.40	4.65	0.745	.0525	15.5	20.51	3 00.5
4.68	0.98	16.5	81.90	4.70	0.980	.0437	20.6	21.02	2 30.3
4.62	1.28	21.0	82.[illegible]0	4.63	1.285	.0427	27.2	21.16	2 2[illegible].5
4.60	1.55	24.0	83.05	4.63	1.5[illegible]0	.0400	3[illegible].0	20.50	2 17.5
4.60	1.88	27.8	83.50	4.63	1.900	.0378	[illegible]	20.05	2 1[illegible].0
4.52	2.17	31.5	83.90	4.57	2.200	.0376	[illegible].3	20.1[illegible]	2 05.8
4.[illegible]0	2.38	3[illegible].5	84.00	4.6[illegible]	2.410	.0346	48.[illegible]	1[illegible].9[illegible]	1 5[illegible].0
4.70	2.80	39.5	84.40	4.72	2.825	.03[illegible]	56.5	20.00	[illegible] 01.0
4.71	3.29	45.6	84.56	4.73	3.3[illegible]5	.0[illegible]4[illegible]	6[illegible]	1[illegible].[illegible]1	1 [illegible]7.6
4.72	3.[illegible]0	47.5	84.58	4.74	3.[illegible]40	.0358	71.[illegible]	1[illegible].[illegible]4	1 52.[illegible]
4.73	3.92	53.0	84.55	4.73	3.975	.0[illegible]72	78.0	19.61	1 [illegible]4.2
4.73	4.42	58.0	84.45	4.75	4.475	.0[illegible]24	87.0	19.44	1 51.4
4.72	4.75	62.5	84.3[illegible]	4.74	4.[illegible]0	.0[illegible]25	93.0	19.37	1 51.7

Circuit #5.

R_s=.3546 L=.0053

I_{ph}	I_2	Defl.	K	$\#I_{ph}$	$\#I_s$	Sin.a	I_p	R	Alpha ° ′
4.87	0.30	14.5	81.22	4.87	0.29	.1265	6.0	20.70	7 1[illegible].0
4.91	0.85	19.5	82.3	4.90	0.85	.0570	17.[illegible]	2[illegible].[illegible]	3 1[illegible].0
4.91	1.27	25.0	83.19	4.90	1.27	.0483	[illegible].50	20.05	2 46.0
4.90	1.80	32.2	8[illegible]. 0	4.89	1.80	.0435	35.30	19.78	2 29.0
4.90	2.35	40.0	84.42	4.89	2.36	.0412	41.20	19.[illegible]5	2 22.0
4.90	3.14	49.6	84.00	4.89	3.13	.0379	51.60	19.50	2 10.0
4.88	3.58	55.5	84.50	4.88	3.62	.0372	70.50	19.50	[illegible] 03.0
4.87	4.12	61.0	84.40	4.87	4.17	.03[illegible]7	81.00	19.40	2 02.8
4.83	4.40	65.0	84.70	4.85	4.45	.0358	88.00	19.30	2 03.9
4.82	4.75	70.8	84.20	4.82	4.78	.0365	92.00	19.20	2 06.0

Circuit #6.

R_s=.3546 L=.0228

I_{ph}	I_2	Defl.	K	$\#I_{ph}$	$\#I_s$	Sin.a	I_p	R	Alpha
4.90	0.30	8.5	79.40	4.89	0.29	.0729	6.5	2[illegible].40	4 11.0
4.92	0.78	12.0	80.70	4.91	0.77	.0390	16.5	21.20	2 15.0
4.88	1.37	15.0	81.48	4.87	1.37	.0[illegible]	[illegible]	20.10	1 35.0
4.88	1.82	18.8	8[illegible].[illegible]5	4.87	1.82	.0[illegible]	35.0	19.78	1 [illegible].0
4.89	2.15	22.0	[illegible]	[illegible]	[illegible].13	.025	4[illegible]	19.53	1 [illegible]6.8
4.88	2.64	25.8	83.65	4.87	[illegible].65	.0[illegible]7	5[illegible].0	19.6[illegible]	1 32.0
4.88	3.08	31.3	83.95	4.87	3.10	.0250	61.0	19.65	1 26.0
4.83	3.53	36.0	84.[illegible]5	4.83	3.56	.0243	70.[illegible]	19.70	1 [illegible]5.0
4.83	4.00	41.	84.50	4.87	4.05	.0249	79.7	19.65	1 26.0
4.85	4.48	47.0	84.59	4.83	4.55	.0254	[illegible].5	19.55	1 [illegible]7.3
4.85	4.37	[illegible].0	84.60	4.85	4.70	.0255	91.5	19.45	1 27.6

Circuit #7.

R_s = .1257 L = .000346

I_{ph}	I_2	Defl.	K	$\#I_{ph}$	$\#I_s$	Sin.a	I_p	R	Alpha ° '
4.91	0.35	11.5	80.60	4.900	0.35	.0835	7.3	20.90	4 48.0
4.90	0.88	21.0	82.62	4.890	1.38	.0497	25.6	20.00	2 51.0
4.89	1.67	31.0	83.85	4.880	1.68	.0450	33.3	19.80	2 35.0
4.88	2.00	35.5	84.23	4.875	2.00	.043[illegible]	39.0	19.50	2 29.0
4.87	2.38	41.5	84.50	4.865	2.40	.0421	46.5	19.35	2 25.0
4.88	2.90	49.0	84.60	4.875	2.95	.0406	57.0	19.45	2 19.5
4.82	3.32	54.0	84.55	4.820	3.37	.0395	65.5	19.40	2 15.1
4.80	3.70	59.0	84.45	4.805	3.75	.0385	72.5	19.32	2 13.0
4.80	4.00	63.5	84.35	4.805	4.05	.0380	78.2	19.30	2 10.6
4.80	4.48	69.5	84.25	4.805	4.52	.0379	87.2	19.28	2 10.31
4.78	4.88	73.5	84.13	4.850	4.92	.0366	94.5	19.20	2 05.9

Circuit #8

R_s .2292 L .000346

I_{ph}	I_2	Defl.	K	$\#I_{ph}$	$\#I_s$	Sin.a	I_p	R	Alpha ° '
4.93	0.35	13.0	81.00	4.915	0.35	.0931	7.8	22.30	5 21.0
4.88	0.88	19.0	82.28	4.875	0.88	.0538	18.2	20.70	3 05.0
4.91	1.33	25.0	83.15	4.900	1.33	.0461	27.0	20.30	2 38.0
4.91	1.70	31.0	83.85	4.900	1.70	.0444	34.0	20.00	2 33.0
4.91	2.15	37.5	84.33	4.900	2.14	.0424	42.0	19.60	2 26.0
4.91	2.55	41.0	84.48	4.900	2.56	.0387	50.2	19.60	2 13.0
4.90	3.00	46.8	84.58	4.890	3.02	.037[illegible]	59.0	19.54	2 09.0
4.8[illegible]	3.50	54.5	84.5[illegible]	4.880	3.54	.0373	69.3	1[illegible].55	2 0[illegible].0
4.90	4.00	62.0	84.37	4.890	4.05	.0371	78.8	1[illegible].45	2 07.0
4.89	4.50	68.0	84.25	4.880	4.95	.0355	95.5	1[illegible].35	1 55.0
4.90	4.925	73.5	84.13	4.890	4.94	.0361	95.6	1[illegible].35	2 04.0

Circuit #10

R_s=.259 L=.000346

I_{ph}	I_2	Defl.	K	$\#I_{ph}$	$\#I_s$	Sin.a	I_p	R	Alpha ° ′
5.00	0.35	16.0	81.70	4.98	0.350	.1121	7.5	21.40	6 [illegible]
4.95	0.62	21.2	82.65	4.94	0.61	.03[illegible]7	13.2	21.40	4 59.5
4.92	1.04	27.0	83.40	4.91	1.04	.0635	[illegible].0	21.20	3 38.5
4.94	1.22	28.0	83.55	4.93	1.23	.0554	[illegible]6.0	21.20	3 10.0
4.91	1.52	33.0	84.05	4.90	1.53	.0525	31.5	20.60	3 00.5
4.85	1.82	35.5	84.33	4.85	1.80	.048[illegible]	37.0	20.50	2 4[illegible].0
4.91	2.03	[illegible]8.5	84.40	4.90	2.04	.0457	42.0	20.55	2 37.0
4.92	2.25	40.2	84.45	4.91	2.29	.0423	46.5	20.30	2 [illegible].6
4.91	2.51	43.5	84.55	4.90	[illegible].5[illegible]	.042[illegible]	51.[illegible]	20.15	[illegible] 2[illegible].0
4.92	2.7[illegible]	46.5	84.58	4.91	2.79	.0399	56.0	20.05	2 17.0
4.95	2.95	[illegible].5	84.30	4.92	3.02	.038[illegible]	60.0	19.90	2 13.0
4.92	3.23	5[illegible].0	84.55	4.91	3.[illegible]8	.0389	6[illegible]	1[illegible].90	2 13.7
4.91	3.5[illegible]	54.5	84.50	4.90	3.57	.0369	70.8	1[illegible].85	2 07.0
3.96	3.50	44.6	84.55	4.09	3.55	.0363	70.5	1[illegible].8	2 05.0
3.96	3.75	48.5	84.60	4.09	3.81	.03[illegible]	7[illegible].2	1[illegible].70	2 06.0
3.92	4.01	50.0	84.58	4.06	4.05	.03[illegible]0	79.5	1[illegible].65	2 03.3
3.90	4.20	53.0	84.55	4.04	4.25	.0358	8[illegible].5	1[illegible].55	2 03.0
3.88	4.50	54.[illegible]	84.55	4.02	4.55	.0350	[illegible].0	19.55	2 00.0
3.9[illegible]	4.67	57.0	84.40	4.06	4.725	.035[illegible]	9[illegible].0	19.45	2 01.0
3.92	4.95	59.0	84.40	4.06	4.99	.0346	9[illegible].0	19.40	1 59.0

Circuit #11

R_s=.[illegible]546 L=.009626

I_{ph}	I_2	Defl.	K	$\#I_{ph}$	$\#I_s$	Sin.a	I_p	R	Alpha ° ′
4.91	0.58	13.5	81.10	4.90	0.575	.0592	13.0	22.60	3 23.6
4.92	1.00	19.2	82.30	4.91	1.000	.0475	21.5	21.50	2 43.3
4.87	1.52	23.5	82.98	4.87	1.463	.0398	30.8	21.05	2 16.9
4.94	2.03	29.5	83.70	4.93	2.040	.0350	41.8	20.50	202.0
4.96	2.55	37.0	84.30	4.95	2.530	.03[illegible]8	51.	20.20	1 59.6
4.96	2.95	41.5	84.50	4.95	2.988	.03[illegible]2	59.8	20.00	1 54.3
4.86	3.54	48.0	84.60	4.86	3.585	.03[illegible]6	71.0	19.80	1 5[illegible].0
4.90	4.00	52.0	84.57	4.89	4.060	.0309	79.8	19.65	1 46.2
4.88	4.50	59.5	84.40	4.88	4.525	.0319	88.5	19.55	1 49.7

Circuit #1[illegible] .

R_s = .212 L = .0346

I_{ph}	I_s	Defl.	E	$\#I_{ph}$	$\#I_s$	Sin. a	I_p	Z	Theta ° ′
4.92	0.35	10.0	80.13	4.90	0.35	.0728	7.5	21.40	4 10.0
4.90	0.80	16.5	81.80	4.89	0.80	.0518	15.7	21.00	2 58.0
4.89	1.32	23.5	82.98	4.88	1.32	.0440	7.2	20.6[illegible]	2 31.[illegible]
4.9[illegible]	1.67	28.5	83.60	4.90	1.69	.0411	34.5	20.40	[illegible] 21.[illegible]
4.90	2.00	33.0	84.03	4.89	2.00	.0401	40.5	20.25	2.18.[illegible]
4.91	2.57	40.0	84.44	4.90	2.58	.0375	51.8	20.08	2 09.0
4.90	3.00	46.0	84.58	4.89	3.0[illegible]	.0368	60.2	19.93	2 06.5
4.91	3.51	51.5	84.58	4.90	3.55	.0350	70.5	19.[illegible]	[illegible] 01.0
4.80	4.03	57.0	84.49	4.80	4.07	.0345	80.8	19.85	1 58.5
4.90	4.50	65.0	84.30	4.89	4.55	.0346	89.6	19.69	1 59.0
4.88	4.97	70.0	84.[illegible]	4.87	4.99	.0340	97.[illegible]	19.[illegible]	1 57.5

Circuit #13.

R_s = .3546 L = .01[illegible]

I_{ph}	I_s	Defl.	E	$\#I_{ph}$	$\#I_s$	Sin. a	I_p	Z	Theta ° ′
4.91	6.35	7.3	79.00	4.90	0.35	.0538	7.5	[illegible]1.40	3 03.[illegible]
4.86	0.85	13.8	81. [illegible]	4.86	0.85	.041[illegible]	18.0	[illegible]1.18	[illegible]
4.88	1.28	19.5	82.37	4.87	1.[illegible]9	.0378	26.8	20.85	[illegible] 10.0
4.88	1.28	22.5	8[illegible]	4.87	1.65	.0358	34.0	20.6[illegible]	1 55.0
4.[illegible]	1.98	26.0	83.30	4.87	2.00	.03[illegible]1	40.8	20.4[illegible]	1 50.0
4.87	2.41	30.5	83.81	4.86	2.4[illegible]	.0310	48.8	20.22	1 47.0
4.88	3.03	38.5	84.40	4.87	3.05	.0308	61.0	20.00	1 46.0
4.88	3.55	43.5	84.5[illegible]	4.87	3.58	.0[illegible]95	70.[illegible]	19.55	1 41.0
4.87	3.98	50.8	84.5[illegible]	4.[illegible]	4.03	.0307	79.5	19.70	1 [illegible].0
4.85	4.50	54.5	84.52	4.85	4.55	.0291	88.0	19.56	1 40.0
4.81	4.80	57.5	83.96	4.81	4.8[illegible]	.0296	94.0	19.50	1 4[illegible].0

Circuit #1.

I_p	Ratio	Alpha ° ′	Ratio Error	Angle Error. 100% Pf.	86.7 Pf.	64.3 Pf.	Total Error. 100 Pf.	86.7 Pf.	64.3 Pf.
10	21.30	3 [illegible]7.0	6.50	.181	3.70	7.45	6.681	10.[illegible]	13.95
20	21.15	2 64.0	5.75	.100	2.75	5.55	5.[illegible]50	[illegible]	11.30
30	20.95	2 [illegible]3.0	4.[illegible]5	.087	[illegible].50	5.[illegible]5	4.[illegible]	7.[illegible]5	[illegible]
40	20.30	[illegible]	3.00	.083	[illegible].50	5.20	3.[illegible]3	[illegible].5	8.[illegible]0
50	20.35	2 1[illegible].0	1.75	.081	[illegible].40	5.00	1.[illegible]31	4.[illegible]	6.75
60	20.15	2 15.5	[illegible].75	.07[illegible]	[illegible].30	4.90	0.[illegible]	3.[illegible]	5.65
70	20.00	2 13.0	[illegible]	.075	[illegible].30	4.75	[illegible]	[illegible].30	4.7[illegible]
80	19.90	2 11.3	-0.[illegible]0	.073	[illegible]	4.10	-0.4[illegible]7	1.8	4.[illegible]0
90	19.72	2 09.0	-1.40	.069	[illegible]	4.30	-1.331	[illegible]	3.[illegible]
100	19.50	[illegible]7.0	-[illegible].50	.068	[illegible]	4.50	-[illegible].15[illegible]	-0.30	[illegible]

Circuit #3.

I_p	Ratio	Alpha ° ′	Ratio Error	Angle Error. 100% Pf.	86.7 Pf.	64.3 Pf.	Total Error. 100 Pf.	86.7 Pf.	64.3 Pf.
10	22.[illegible]	3 [illegible]4.0	14.[illegible]	[illegible]	4.30	[illegible].30	14.48[illegible]	1[illegible].55	[illegible]
20	21.60	2 56.0	8.0	.134	3.10	[illegible].55	8.134	11.10	14.55
30	20.92	2 3[illegible].0	4.60	.098	2.70	5.30	4.[illegible]98	7.30	9.95
40	20.50	2 19.0	[illegible].50	.[illegible]82	2.50	4.90	[illegible].582	5.00	7.40
50	20.20	2 10.0	1.00	.071	2.40	4.50	1.071	[illegible].40	5.50
60	19.92	2 03.5	-0.40	.063	2.[illegible]5	4.30	-.337	1.85	3.90
70	19.70	1 59.0	-1.50	.060	2.20	4.20	-1.440	0.70	2.70
80	1[illegible].50	1 55.5	-2.50	.056	2.15	4.10	-2.444	-0.35	1.60
90	19.36	1 53.0	-3.20	.054	2.05	[illegible].00	-3.146	-1.15	0.70
100	19.28	1 51.0	-3.60	.052	2.00	3.[illegible]0	-3.548	-1.60	0.20

Circuit #4.

I_p	Ratio	Alpha ° ′	Ratio Error	Angle Error. 100% Pf.	86.7 Pf.	64.3 Pf.	Total Error. 100 Pf.	86.7 Pf.	64.3 Pf.
10	23.02	3 36.5	1[illegible].10	.198	4.00	7.65	5.[illegible]9[illegible]	9.10	12.75
20	20.70	2 44.0	[illegible].50	.114	3.90	6.50	3.614	7.40	10.00
30	20.41	2 20.5	[illegible].05	.083	3.50	5.00	[illegible].133	5.55	7.05
40	20.16	2 08.5	0.90	.069	3.30	4.50	0.869	4.10	5.30
50	1[illegible].95	2 01.0	-0.2[illegible]	.06[illegible]	3.20	4.30	-0.1[illegible]	[illegible].95	4.05
60	19.79	1 56.0	-1.07	.057	3.15	4.20	-1.013	2.08	3.13
70	1[illegible]	1 54.0	-1.60	.055	3.10	4.10	-1.[illegible]45	1.30	2.50
80	1[illegible].63	1 52.0	-1.85	.053	3.05	3.90	-1.797	1.20	2.05
90	19.62	1 52.0	-1.90	.053	3.05	3.90	-1.847	1.15	2.00
100	19.62	1 52.0	-1.90	.0[illegible]	3.05	3.90	-1.847	1.15	2.00

Circuit #5.

I/I	Ratio	Alpha ° ′	Ratio Error	Angle Error 100% P.F.	Angle Error 86.7 P.F.	Angle Error 64.3 P.F.	Total Error 100% P.F.	Total Error 86.7 P.F.	Total Error 64.3 P.F.
10	[illegible]	[illegible] 51	[illegible].60	.52	6.50	1[illegible].8	[illegible].12	[illegible].10	1[illegible].40
20	20.15	3 05	[illegible].75	.15	3.40	[illegible]	[illegible].00	4.15	[illegible].55
30	19.90	2 38	-0.[illegible]	0.11	3.30	5.7	-0.7[illegible]	2.50	3.20
40	19.70	2 25	-1.50	0.09	2.70	5.3	-1.41	1.20	3.80
50	19.56	2 18	-2.1[illegible]	0.08	2.50	[illegible]	-2.07	0.35	3.05
60	19.50	2 12	-2.50	0.08	2.40	5.0	-2.42	-0.10	2.50
70	19.46	2 08	-2.70	0.07	2.30	4.7	- .63	-0.40	2.00
80	19.40	2 02	-3.00	0.06	2.20	4.5	-2.94	-0.80	1.50
90	19.25	1 56	-3.75	0.06	2.10	4.3	-3. 9	-1.65	0.55
100	19.00	1 52	-5.00	0.05	2.00	4.0	-4.95	- .00	-1.00

Circuit #6

I/I	Ratio	Alpha ° ′	Ratio Error	Angle Error 100% P.F.	Angle Error 86.7 P.F.	Angle Error 64.3 P.F.	Total Error 100% P.F.	Total Error 86.7 P.F.	Total Error 64.3 P.F.
10	21.95	3 20	[illegible]	0.17	[illegible].70	7.2	10. 5	1[illegible].54	17.08
20	20.75	1 54	3.75	0.05	2.00	[illegible].3	3. 1	5.75	[illegible].05
30	19.90	1 33	-0.50	0.04	1.80	7.5	-0.46	1.30	3.00
40	19.70	1 27	1.50	0.03	1.70	3.[illegible]	-1.47	0.20	1.70
50	19.63	1 26	-1.85	0.03	1.60	3.0	-1. 2	-0.25	1.15
60	19.65	1 23	-1.75	0.03	1.50	3.00	-1.72	-0.15	1.25
70	19.70	1 26	-1.50	0.03	1.60	3.0	-1.47	0.10	1.50
80	19.65	1 23	-1.75	0.05	1.60	3.0	-1.72	-0.15	1.25
90	19.50	1 27	-2.50	0.03	1.70	[illegible]	-2.47	-0.80	0.07
100	19.30	1 28	-3.50	0.03	1.60	3.3	-3.47	-. 0	-0.20

Circuit #7.

I/I	Ratio	Alpha ° ′	Ratio Error	Angle Error 100% P.F.	Angle Error 86.7 P.F.	Angle Error 64.3 P.F.	Total Error 100% P.F.	Total Error 86.7 P.F.	Total Error 64.3 P.F.
10	20.70	4 24	3.50	[illegible]	4.[illegible]0	9.5	3.71	8.50	13. [illegible]
20	20.15	3 12	0.75	0.16	3.50	6.7	0.91	4.[illegible]	[illegible].45
30	19.85	2 41	-0.75	0.11	3.[illegible]	5.8	-0.04	2.26	5.[illegible]5
40	19.65	2 28	-1.75	0.09	2.70	5.3	-1.[illegible]	0.95	3. 5
50	19.52	2 22	-2.40	0.09	2.50	5.2	-2.31	0.10	2. 0
60	19.41	2 18	-2.95	0.08	2.50	5.1	-2.87	-0.45	+2.05
70	19.35	2 14	-3.25	0.08	2.30	4.9	-3.17	-0.95	+1.65
80	19.28	2 11	-3.60	0.07	2.30	4.9	-3.53	-1.30	1.20
90	19.22	2 08	-3.90	0.07	2.30	4.7	-3.83	-1.60	0.80
100	19.18	2 06	-4.60	0.07	2.20	4.5	-4.53	-2.40	-0.10

Circuit #8.

I/I	Ratio	Alpha ° ′	Ratio Error	Angle Error 100% P.F.	Angle Error 86.7 P.F.	Angle Error 64.3 P.F.	Total Error 100% P.F.	Total Error 86.7 P.F.	Total Error 64.3 P.F.
10	21.7	4 27	[illegible].75	[illegible].30	4.80	[illegible].5	9.05	13.55	18.[illegible]
20	20.62	3 01	3.10	0.17	3.20	6.5	3.23	[illegible].30	9.60
30	20.08	2 37	0.40	0.10	2.80	5.7	0.50	3.20	6.10
40	19.95	2 24	-0.25	0.09	2.40	5.3	-0.16	2.15	5.00
50	19.56	2 15	-2.20	0.08	2.30	4.9	-2.12	0.10	[illegible].70
60	19.50	2 11	-2.50	0.07	2.30	4.80	-2.43	-0.20	2.30
70	19.48	2 09	-2.60	0.07	2.30	4.7	-2.53	-0.30	[illegible].10
80	19.45	2 07	-2.75	0.07	2.20	4.6	-2.[illegible]	-0.55	1.80
90	19.40	2 06	-3.00	0.07	2.20	4.5	-2.93	-0.80	1.50
100	19.30	2 04	-3.50	0.07	2.15	4.4	-3.43	-1.35	0.90

Circuit #10.

I	Ratio	Al r (° ′)	Ratio Error	Angle Error 100 P.F.	[illegible]6.7 P.F.	54.3[illegible] P.F.	Total Error 100 P.F.	[illegible] P.F.	[illegible] P.F.
10	21.50	5 4[illegible]	7.50	.500	5.3[illegible]	1[illegible].3	[illegible].000	13.75	19.[illegible]0
20	[illegible]0.99	[illegible] 57	[illegible].90	.2[illegible]	4.20	[illegible]	5.1[illegible]3	[illegible].10	13.50
30	20.65	3 07	3.75	.148	3.[illegible]5	6.7	3.39[illegible]	7.00	10.45
40	20.37	2 39	1.85	.107	2.75	5.7	1.937	4.60	7.55
50	20.16	2 23	0.90	.087	2.40	5.0	0.[illegible]87	3.20	5.[illegible]0
60	19.97	2 14	-0.15	.075	2.25	4.6	-0.075	2.10	4.30
70	19.80	2 09	-1.00	.06[illegible]	2.2[illegible]	4.5	-0.971	1.23	3.50
80	19.65	2 04	-1.75	.063	2.20	4.4	-1.[illegible]67	0.47	[illegible].65
90	19.50	2 01	-2.50	.062	2.20	4.4	-2.438	-0.30	1.90
100	19.35	1 59	-3.[illegible]	.060	2.20	4.3	-3.1[illegible]0	-1.05	1.05

Circuit #11.

I	Ratio	° ′	Ratio Error	Angle Error 100 P.F.			Total Error 100 P.F.		
10	23.00	3 4[illegible]	15.00	.[illegible]10	4.05	8.10	15.[illegible]10	19.05	[illegible].10
20	21.84	2 4[illegible]	9.[illegible]0	.121	2.95	[illegible].6	9.321	12.15	15.[illegible]0
30	21.06	2 19	5.30	.082	2.45	[illegible].0	5.[illegible]	7.75	10.30
40	20.57	[illegible] 04	2.85	.065	2.20	4.5	2.[illegible]13	5.05	7.30
50	20.23	1 5[illegible]	1.15	.057	2.1[illegible]	4.5	1.207	3.30	5.45
60	19.99	1 54	-0.05	.055	2.1[illegible]	4.2	0.005	[illegible].07	4.1[illegible]
70	19.81	1 50	-0.95	.051	2.10	4.0	-0.899	1.1	3.05
80	19.65	1 4[illegible]	-1.75	.050	2.00	3.9	-1.700	0.25	2.1[illegible]
90	19.55	1 4[illegible]	-2.25	.050	2.00	3.9	-[illegible].200	-0.25	1.65
100	19.44	1 49	-2.80	.050	2.00	3.9	-[illegible].750	-0.80	1.10

Circuit #12.

I	Ratio	° ′	Ratio Error	Angle Error 100 P.F.			Total Error 100 P.F.		
10	21.29	3 [illegible]9	6.45	.203	4.00	7.7	[illegible].353	10.45	14.15
20	20.85	2 47	4.25	.118	2.95	5.9	4.368	7.20	10.15
30	20.52	2 [illegible]6	2.60	.090	2.55	5.[illegible]	2.6[illegible]0	5.15	7.75
40	20.25	2 1[illegible]	1.25	.077	2.[illegible]5	4.[illegible]	1.3[illegible]7	3.70	6.00
50	20.08	2 08	0.40	.069	2.35	4.5	0.469	2.75	4.90
60	19.97	2 03	-0.15	.065	2.[illegible]0	4.3	-0.085	2.05	4.15
70	19.86	2 00	-0.70	.061	2.1[illegible]	4.3	-0.[illegible]	1.45	3.65
80	19.80	1 59	-1.00	.060	2.10	4.2	-0.940	1.10	3.20
90	19.70	1 58	-1.50	.059	2.05	4.2	-1.441	0.55	[illegible].65
100	19.57	1 57	-2.15	.058	2.00	4.1	-[illegible].09[illegible]	-0.15	1.95

Circuit #13.

I	Ratio	° ′	Ratio Error	Angle Error 100 P.F.			Total Error 100 P.F.		
10	[illegible]1.37	[illegible] 5	[illegible].85	.135	[illegible].00	6.0	[illegible].97[illegible]	[illegible].8[illegible]	1[illegible].8[illegible]
20	21.09	2 20	5.45	.0[illegible]	2.50	4.9	5.5[illegible]3	7.[illegible]	10.40
30	20.71	2 00	3.55	.0[illegible]1	[illegible].15	4.3	3.[illegible]11	[illegible].70	7.[illegible]0
40	20.40	1 50	2.00	.051	1.90	3.6	2.051	3.[illegible]0	5.[illegible]0
50	20.15	1 47	0.80	.0[illegible]	1.80	[illegible].6	0.[illegible]4	[illegible].60	4.40
60	19.98	1 45	-0.[illegible]0	.047	1.75	3.[illegible]	-0.154	1.55	[illegible]
70	19.80	1 44	-1.00	.0[illegible]6	1.74	[illegible].5	-0.954	0.74	[illegible].54
80	1[illegible].66	1 4[illegible]	-1.70	.045	1.7[illegible]	3.5	-1.[illegible]	0.0[illegible]	1.6[illegible]
90	19.53	1 4[illegible]	-2.[illegible]	.044	1.7[illegible]	[illegible].5	-[illegible].[illegible]06	-0.[illegible]	1.1[illegible]
100	1[illegible].40	1 41	-3.00	.04[illegible]	1.[illegible]0	[illegible].5	-[illegible].9[illegible]7	-1.30	0.[illegible]0

Ratio Readings.

Constant Resistance.

I_p	Circuit 4	5	11	13	6
			RATIO.		
20	20/70	20.1	21.84	21.10	20.7[illegible]
40	20.16	19.70	20.57	20.40	19.70
60	19.79	19.50	19.99	19.96	19.66
80	19.63	19.40	19.65	19.35	19.65
100	19.62	19.00	19.44	19.40	19.30

Constant Reactance.

Circuit	1	7	12	8	10
20	21.15	20.1	20.[illegible]6	20.65	20.98
40	20.60	19.65	20.25	19.95	20.37
60	20.16	19.41	19.95	19.50	19.97
80	19.90	19.[illegible]	19.[illegible]0	19.45	19/65
100	19.50	19.18	19.55	19.30	19.35

Angle Readings.

Constant Resistance.

Circuit	4 °	′	5 °	′	11 °	′	13 °	′	6 °	′
20	2	44	3	05	[illegible]	20	[illegible]	4[illegible]	1	[illegible]
40	2	09	[illegible]	[illegible]5	[illegible]	04	1	50	1	27
60	1	56	[illegible]	13	1	54	1	45	1	[illegible]
80	1	52	2	02	1	49	1	43	1	27
100	1	52	1	52	1	49	1	42	1	28

Constant Reactance.

	1 °	′	7 °	′	12 °	′	8 °	′	10 °	′
20	2	34	[illegible]	12	2	47	3	01	3	07
40	2	20	2	28	2	15	2	24	[illegible]	59
60	2	16	2	13	2	04	2	11	2	14
80	2	11	2	11	1	59	2	07	2	04
100	2	07	2	06	1	56	2	04	1	59

Errors for 80% Power Factor.

Constant R. Variable L.

L	.0050	.0075	.0100	.0150	.0175	.0200
		[illegible]0	Amperes.			
Ratio	1.2[illegible]	4.[illegible]0	8.15	[illegible].[illegible]0	3.40	4.50
Alpha	4.20	4.20	7.70	7.[illegible]0	3.00	2.50
Total	5.4[illegible]	[illegible].00	11.65	[illegible].[illegible]0	[illegible].40	7.30
		40	Amperes.			
Ratio	-0.90	-0.50	2.60	2.65	1.60	-1.50
Alpha	3.10	3.00	2.70	2.50	2.40	2.00
Total	2.10	2.50	5.30	5.15	4.00	0.50
		60	Amperes.			
Ratio	-1.40	-0.[illegible]	0.00	0.25	-0.25	-1.75
Alpha	2.80	2.70	2.50	2.40	2.30	2.00
Total	1.40	1.95	2L50	2.65	2.05	0.25
		80	Amperes.			
Ratio	-2.90	-2.65	-1.90	-1.60	-1.60	-1.75
Alpha	2.60	2.50	2.40	2.30	2.30	2.00
Total	-0.30	-0.15	0.50	0.70	0.70	0.25
		100	Amperes.			
Ratio	-3.40	-3.60	-2.95	-2.85	-2.95	-3.45
Alpha	+0.90	2.50	2.40	2.30	2.30	2.00
Total	-0.90	-1.10	-0.55	-0.55	-0.65	-1.45

Constant L. Variable R.

R	0.09	0.1[illegible]	0.1[illegible]	0.20	.024
Ratio	5.65	1.50	-0.50	0.50	3L15
Alpha	3.50	4.30	4. 0	4.80	4.50
Total	9.1[illegible]	5.80	3.70	5.30	7.70
		40	Amperes		
Ratio	4.00	-1.25	-[illegible].35	-1.75	0.50
Alpha	3.20	3.30	3.20	3.00	3.30
Total	7.20	2.05	0.85	1.[illegible]5	2.60
		60	Amperes.		
Ratio	0.75	-[illegible].[illegible]5	-3.50	-3.35	-1.75
Alpha	3.00	3.[illegible]0	3.80	[illegible].70	2.90
Total	3.75	0.95	0.70	-0.65	1.25
		[illegible]0	Amperes.		
Ratio	-0.50	-5.10	-4.2[illegible]	-[illegible].95	-[illegible].50
Alpha	+2.90	3.00	2.70	2.60	2.80
Total	2.40	-0.10	-1.35	-1.35	0.30

Data for Calibration Curves.

Hot Wire with Shunt.

I_{st}	$I_{H.W.}$
13.2	10.0
23.0	20.0
31.0	30.0
41.5	40.0
51.0	50.0
61.255	60.0
71.5	70.0
81.75	80.0
92.0	90.0
102.0	100.0

Hot Wire no Shunt.

I_{st}	I_{HW}
0.3[illegible]	10.0
0.65	20.0
0.93	30.0
1.23	40.0
1.54	50.0
1.85	60.0
2.15	70.0
2.43	80.0
2.71	90.0
2.98	100.0

Hot Wire Against I_2

I_2	I_{HW}
0.70	0.70
1.25	1.25
1.655	1.70[illegible]
2.00	2.005
2.415	2.43
2.97	2.98

Hot Wire as Voltmeter.

I_{st}	E_M
14.3	.037
25.2	.061
35.0	.093
41.6	.111
56.8	.150
69.5	.184
78.[illegible]	.215
93.0	2255
101.0	.280

Calibration of E_M.

E_{st}	E_M
.030	.032
.060	.063
.100	.105
.130	.132
.160	.165
.200	.208
.230	.235
.260	.267
.300	.308

Voltmeter 4403.

E_{st}	E
0.30	0.31
0.40	0.41
0.60	0.61
0.80	0.82
1.00	1.015
1.50	1.515
2.00	2.065

Dynamometer against I_2 and I_{ph}

D.	I_2	I_{ph}
13.5	2.915	2.90
15.0	3.150	3.15
17.0	3.340	3.34
20.0	3.630	3.62
21.6	3.860	3.84
24.0	4.050	4.05
27.0	4.280	4.29
29.0	4.490	4.49
31.30	4.700	4.69
33.5	4.850	4.84

Dynam. as Ammeter.

D	I_{st}
5.50	2.00
7.00	2.25
10/20	2.75
1[illegible].35	3.00
14.50	3.[illegible]
16.[illegible]	[illegible].50
19.70	3.75
2[illegible].20	4.00
[illegible]5.30	4.25
[illegible].50	4.50
3[illegible].00	4.75
[illegible].25	5.00

Ammeter 106.

I_{st}	I
1.00	1.00
2.00	2.03
3.00	3.06
4.00	4.10
4.85	5.00

Ratio Readings for Transformer 2.

25 Ampere Shunt used.

#1.		#3.		#4.		#10.		#11.	
I_H	I_2	I_H	I_2	I_H	I_2	I_H	I_2	I_H	I_2
3.0	0.70	2.5	0.65	2 2.5	0.54	3.0	0.74	2.5	.61
5.0	1.17	6.5	1.44	5.0	1.13	5.0	1.16	5.0	1.12
10.0	2.13	10.0	2.12	10.0	2.09	10.0	2.13	10.0	2.09
12.5	2.62	12.5	2.59	12.5	2.59	12.5	2.62	12.5	2.59
15.0	3.15	15.0	3.13	15.0	3.12	15.0	3.17	15.0	3.11
16.0	3.35	17.5	3.72	17.4	3.65	17.5	3.70	16.0	3.52
17.5	3.73	18.25	3.80			19.0	3.98		
20.0	4.20								

Data on Transformer [illegible]

Circuit [illegible]1.

I_{ph}	I_2	Defl.
4.90	0.[illegible]	3.0
4.92	0.82	13.8
4.92	1.[illegible]	1[illegible]
4.90	1.[illegible]3	26.8
4.91	1.93	30.5
4.92	2.17	[illegible]
4.90	[illegible].38	32.0
4.89	[illegible].72	[illegible].4
4.93	3.07	42.3
4.93	3.36	45.5
3.[illegible]3	3.60	40.0
3.90	3.[illegible]7	43.8
[illegible]	4.13	47.9
[illegible].[illegible]0	4.3[illegible]	50.0

Circuit [illegible].

I_{ph}	I_2	Defl.
5.0[illegible]	[illegible]	[illegible]
4.9[illegible]	[illegible].7[illegible]	15.[illegible]
5.01	1.14	[illegible]
5.00	1.4[illegible]	[illegible]
4.90	1.[illegible]	[illegible].5
5.0[illegible]	[illegible].0[illegible]	30.[illegible]
4.9[illegible]	[illegible].30	34.8
4.94	[illegible]	[illegible]
4.[illegible]	[illegible]	4[illegible].0
[illegible].9[illegible]	[illegible].30	46.0
[illegible].95	[illegible].4[illegible]	[illegible].0
[illegible]	[illegible].75	[illegible]4.0
[illegible].95	4.00	[illegible]
[illegible].95	4.15	4[illegible]

Circuit 4.

I_{ph}	I_2	Defl.
[illegible]	[illegible]	[illegible]
[illegible]	0.[illegible]	11.[illegible]
[illegible].93	1.10	19.[illegible]
[illegible]	1.40	[illegible].0
[illegible]	1.[illegible]	3[illegible]
[illegible].95	[illegible].05	3[illegible]
[illegible].9[illegible]	[illegible].35	[illegible].2
4.9[illegible]	[illegible].75	43.5
4.8[illegible]	3.[illegible]	4[illegible].0
4.8[illegible]	3.[illegible]5	49.[illegible]
3.8[illegible]	3.50	[illegible]2.8
3.85	[illegible]	[illegible]7.0
3.80	3.90	47.7
3.75	4.00	4[illegible]

Circuit [illegible]11.

I_{ph}	I_2	Defl.
4.91	0.[illegible]	[illegible].0
4.9[illegible]	0.[illegible]	14.5
4.95	1.02	17.5
4.9[illegible]	1.30	21.[illegible]
4.8[illegible]	1.54	25.0
4.8[illegible]	1.90	30.8
4.91	[illegible].25	32.5
4.95	2.50	35.8
4.95	2.75	39.5
4.90	3.00	42.0
4.91	3.30	45.5
3.94	3.52	38.5

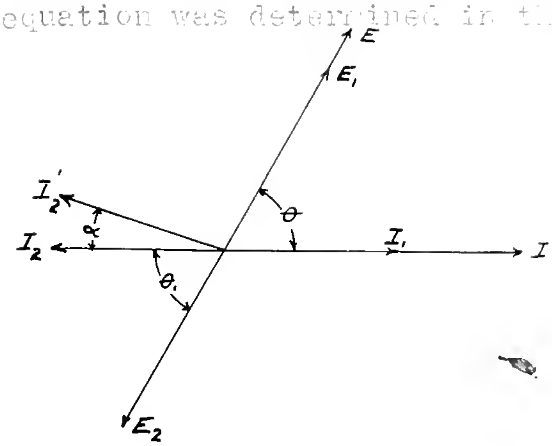
Circuit #10.

I_{ph}	I_2	Defl.
4.90	0.[illegible]0	7.0
4.8[illegible]	0.75	15.0
4.90	1.20	23.5
5.00	1.55	[illegible].5
4.90	1.[illegible]	[illegible]7.5
4.91	2.[illegible]	34.8
5.00	2.4[illegible]	40.0
4.93	2.80	43.2
4.98	3.[illegible]	46.5
4.99	[illegible].51	50.5
5.00	3.87	56.0
5.00	4.00	5[illegible].4

By means of the calibration curves of the various instruments used in the test, the data was corrected, the corrected values being used as the basis of all the curves. The preliminary curves were then drawn for each circuit with the primary current as abscissas and the ratio and the angle alpha as ordinates. From these curves values were picked for additional curves, and for convenience these values were taken for every ten amperes as shown on data sheets pp.22-25.

From these values the ratio error, angle error, and total error were determined. Evidently the ratio error in percent is equal to 100(apparent ratio- true ratio)/ (true ratio), and since the true ratio is 20, the formula resolves itself into ratio error 100(apparent ratio-20)/20. A study of the ratio relations between the primary and the secondary of the series transformer, and the above equation shows that necessarily positive values of error are in favor of the consumer, since more current is flowing than is measured, and hence negative values are in favor of the station.

The percentage angle error may be determined from the formula percent error $100(1-\cos(a+\theta)/\cos\theta)$, where alpha is the error angle as determined in preceding data, and theta is the angle of phase difference between the primary e.m.f. and current. The above equation was determined in the following manner:



Let E = E. M. F. on mains, and I = current in main, and $\cos\theta$ = power factor. Then the power supplied = $EI\cos\theta$. In the series transformer E_1 of the primary = KE, and I_1 of the primary = K I, and $\cos\theta$ is common,

thus $E_1 I_1 \cos\theta = K E I \cos\theta$, that is, the power in the primary of the transformer is proportional to the power in the line. Assuming ideal transformer relations and a ratio of 1 to 1, the latter merely for convenience as any ratio will lead to the same result, then $I_2 = I_1$ and is 180 degrees out of phase with it, also $E_2 = E_1$ and is 180 degrees out of phase with it, hence, $E_2 I_2 \cos\theta = E_1 I_1 \cos\theta = K_3 E I \cos\theta$, which states that $E_2 I_2 \cos\theta$ is a measure of the true power supplied, based on ideal conditions. Due to the resistance and the reactance of the transformer the phase angle difference in the primary and the secondary may differ by some small angle alpha, and hence the power registered on the secondary side would be $E_2 I_2' \cos(\theta + a)$, and since $E_2 = E_1$ and $I_2' = I_1$, the power registered would be $E_1 I_1 \cos(\theta + a)$. The error would then be $100(E_1 I_1 \cos\theta - E_1 I_1 \cos(\theta + a))/E_1 I_1 \cos\theta = 100(1 - \cos(\theta + a)/\cos\theta)$.

As the angle is a lag angle, the error caused thereby is always in favor of the consumer, and is therefore considered a positive error. The algebraic sum of the ratio error and the angle error gives the total error. It is this total error which is used as ordinates in curves 13-24. A study of the data for these error curves shows that the total error for 100% power factor and the ratio error differ only slightly, so that only the ratio error curve for 100% power factor was plotted.

A series of angle and ratio values were taken from the circuit curve, for 25%, 50%, 75%, 100%, and 125% of full load, grouping those results with the same resistance and variable reactance, and also those with the same reactance and variable resistance. In the first case the angle alpha and the ratio were plotted against the reactance, while in the latter case they were plotted against the resistance.

For points on these curves, the error was calculated and plotted against resistance and inductance. Circuit #10, the nearest approach to practical conditions, with a resistance equal to that of 100 feet of #14 B. S. wire and a low inductance, was then selected, and the total error for different power factors plotted against power factor, for different loads. A sample calculation of the above is shown in the following:

Circuit #10 on page [illegible] is taken as the standard because it is the nearest to actual conditions.

$I_{ph}=5.00$ #$I_{ph}=4.98$ $I_s=0.75$ #$I_s=$[illegible] Defl.=[illegible] R=51.70

$$\sin a = \frac{16.0}{4.98 \times 0.75 \times 51.70} = .1121 \qquad a = [illegible]$$

From ratio readings on page 13 a curve was plotted between the primary and secondary currents. Then by taking I_p corresponding to secondary current $I_s=0.75$, a value of $I_p=7.5$ was obtained. This gives a ratio of 7.5/5.5=21.40. These values of ratio and alpha are plotted against I_p on curve sheet #9. Points picked off of these curves for every ten amperes are tabulated on page 24.

From this data take $I_p=20$. Then ratio is 20.98 and % error is 100(20.98 - 20.00)/20 or 4.90%. Alpha for same I_p is 3°57.0'.

% Error = $100 - 100\cos(\theta + a)/\cos\theta$. For an 86.7% power-factor $\theta=30°$ and $(\theta + a)=33°57.0'$. Cos30°=[illegible] Cos33°57'=.8295.

This gives an error of 4.2%. Total error is 4.9 + 4.2=9.1%. Values obtained as above are plotted against I_p on curve sheet #10.

Page 25 gives the values of ratio and alpha for the different circuits where R is constant and L is variable and also where L is constant and R is variable. These plotted against R and L give curve sheets 14 and 15. The errors for the same for 80% power-factor are tabulated on page [illegible] and the curves plotted from this data are on curve sheets 16 and 17.

A general consideration of the curves leads to the following conclusions;

Ratio, Angle, - I_p Curves.

The ratio and the angle decrease with increased load and so does the error due to these.

Angle - Resistance Curves.

The angle approaches zero for zero resistance. A maximum occurs at .15 ohms. A minimum at .30. An increase of load straightens out the curves and tends to make the angle error constant for all resistancees. It also decreases the angle.

Ratio - Resistance Curves.

Transformer circuit has a critical resistance which gives minimum value to the ratio either a decrease or increase in the resistance raising the ratio. For any resistance an increase in load decreases the value of the ratio. Curves show that there are two resistances that will give the true value to the ratio for any load.

Angle - Inductance Curves.

The angle decreases with load. The critical value of inductance at which angle is a maximum is .006 henrys. An increase or decrease in the inductance decreases the angle.

Ratio - Inductances.

An increase in the inductance lowers the ratio and makes it more constant. For high loads the ratio is nearly constant for all values of L. The curves indicate a critical maximum and a minimum.

Power factor - Error.

The error decreases with an increased power factor.

Resistance - Error Curves.

The total error varies ~~directly~~ inversely as the load and may be negative. There is a critical value of R which gives a minimum error.

Inductance - Error Curves.

The total error varies inversely as the load and may be negative. A critical value of R gives a maximum error.

A consideration of the above shows that the inductance and resistance in the secondary play an important part in the correct operation of the series transformer for switch-board use. Where the instrument leads and transformer are calibrated together and used together the errors shown in the curves are eliminated. But this is not the practice as the position of the instruments may be changed or the resistance of the leads is not determined at the time of calibration.

That this is an important consideration is shown by the fact that the errors in some of the circuits approach very large values on light loads and values that cannot be neglected even on the usual operating loads. The average error will introduce a loss to any station sufficiently large to make it worth while for them to investigate this error.

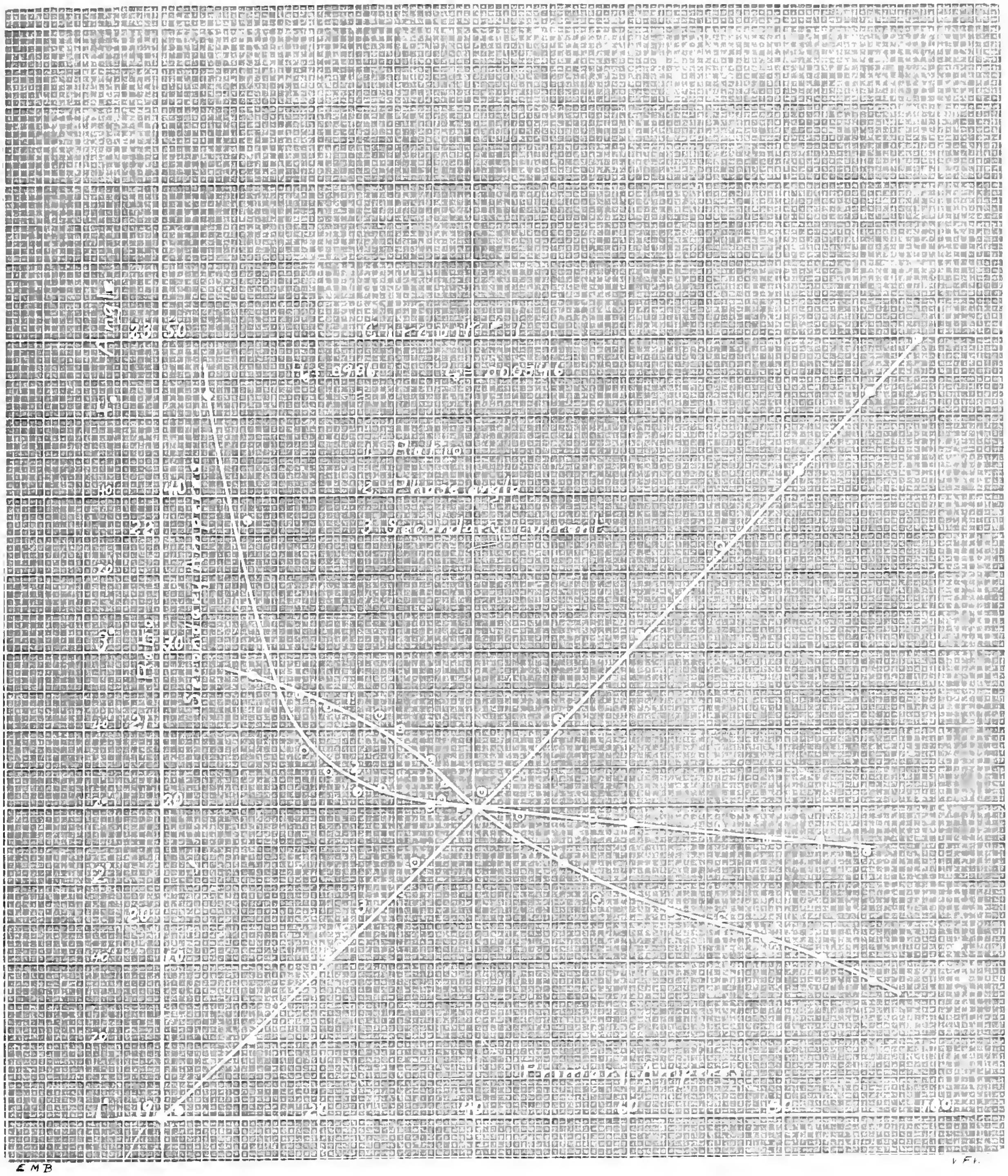
It is customary in making a series transformer test to merely test the ratio of transformation. This of course is based on the assumption that the current and e.m.f. in the secondary of the transformer bear the same relation to each other that the current and e.m.f. in the primary do, or if not, that the error introduced thereby is negligible. That this is a serious mistake will [illegible]

after a study of the curves [illegible].

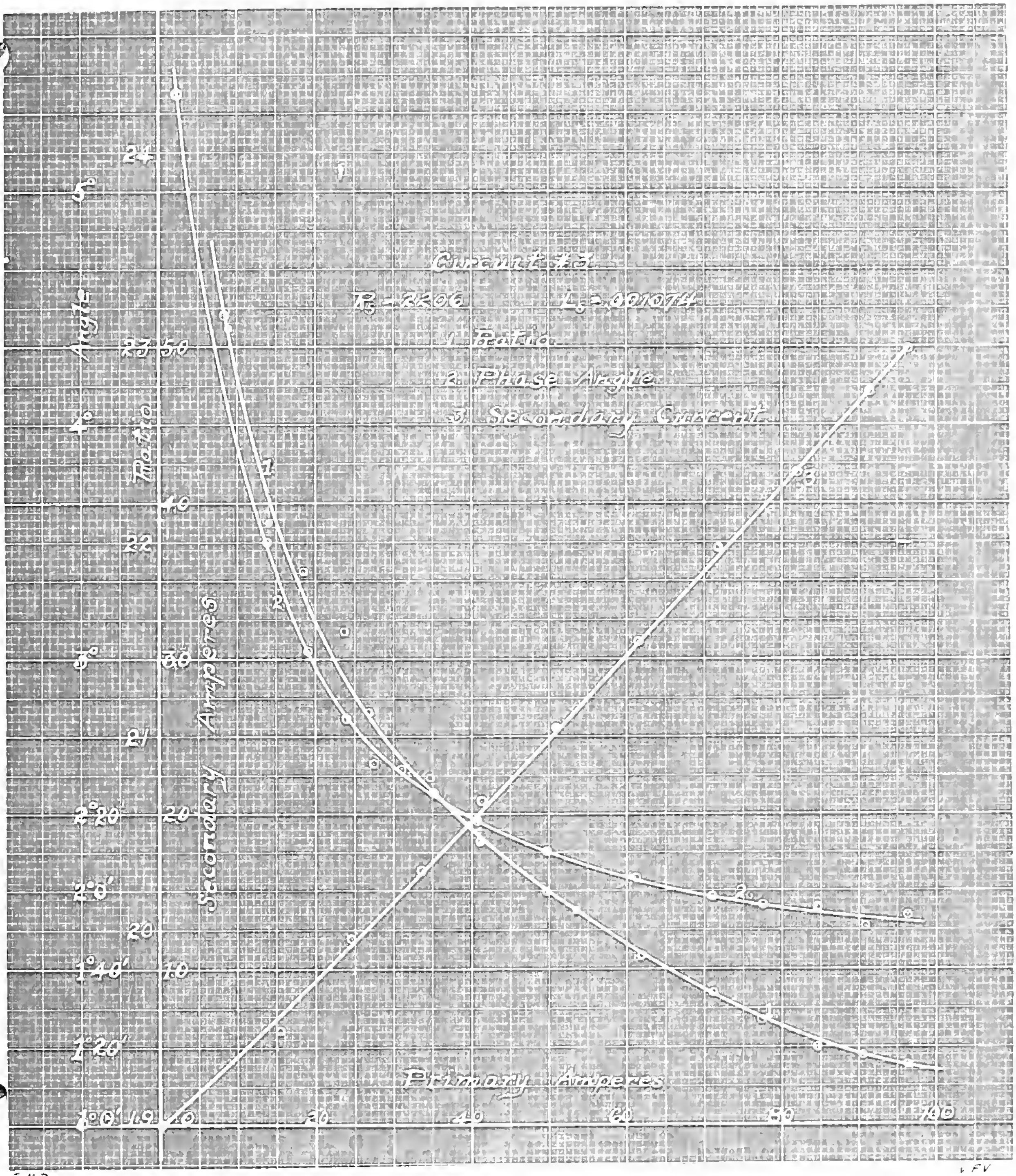
It will be noted that at about the usual operating power factor at light loads, the error due to the phase difference of the current and e.m.f. in the secondary [illegible] that due to the ratio, while at normal operating loads it is equal to or slightly greater than the ratio error. For full loads the angle error is usually smaller than the ratio error, and for power factors of 100% or nearly so, the angle error can be neglected. When the usual operating power factor is often much below 100%, the error due to the phase angle should also be considered in connection with that due to the ratio.

E.M.B.

V.F.

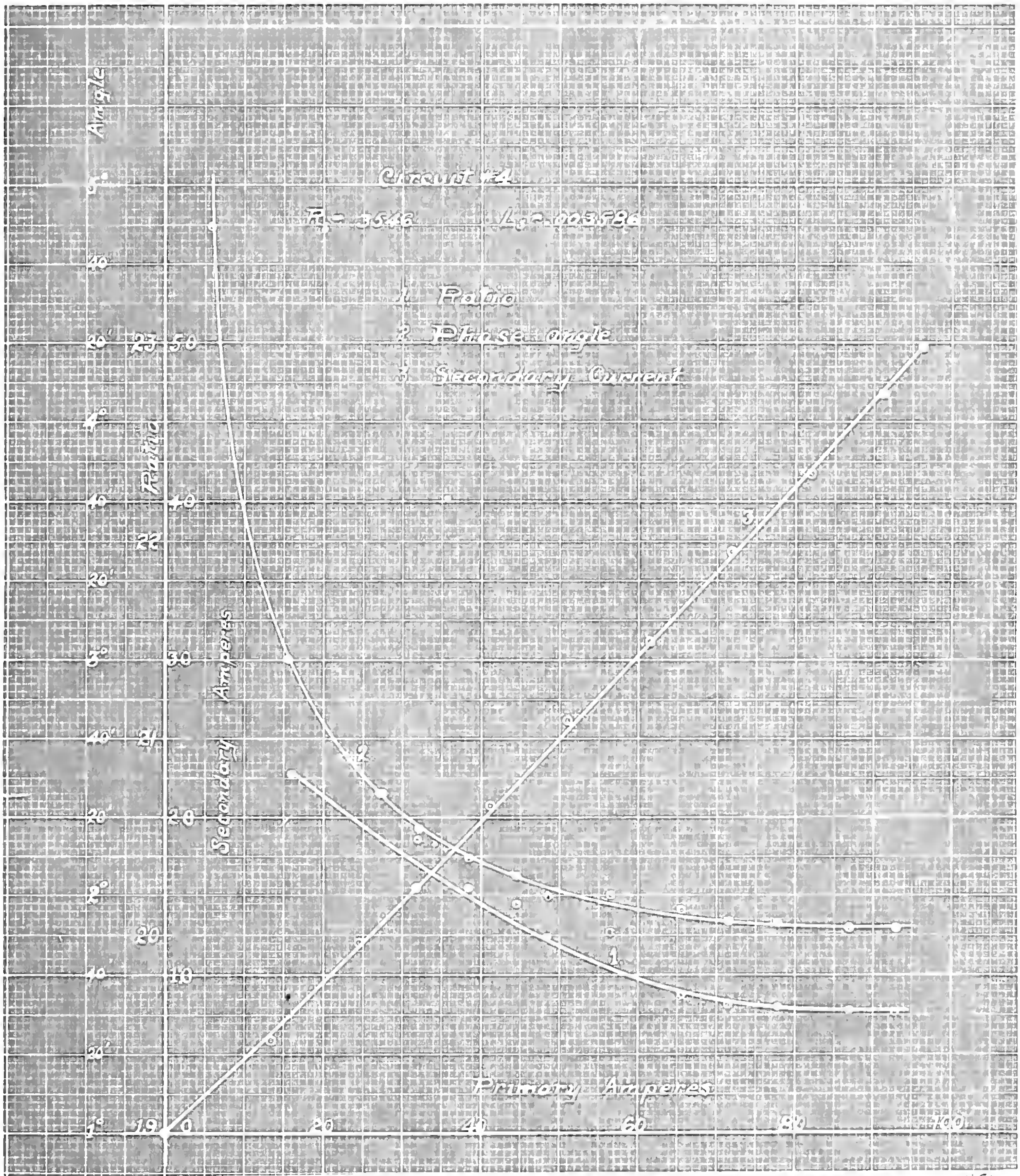

1. Ratio
2. Phase angle
3. Secondary current
Angle
Ratio
Secondary Amperes
Primary Amperes
20
40
60
80
100

EMB

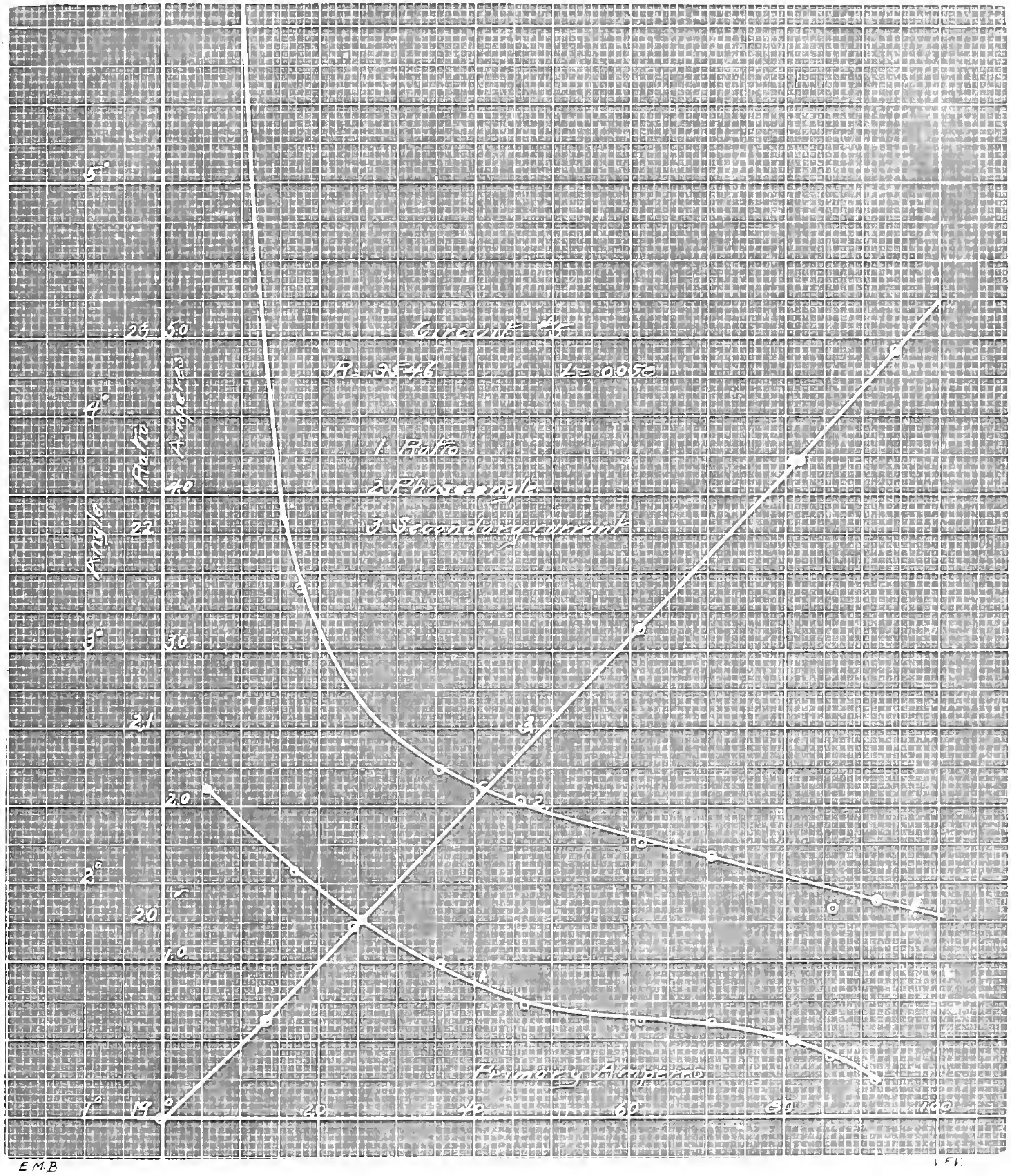


Circuit #3
R_s = .2206 L_s = .001074
1 Ratio
2 Phase Angle
3 Secondary Current
Angle
Ratio
Secondary Amperes
Primary Amperes
24
5°
23 50
4°
40
22
3°
30
21
2°20'
20
2°0'
20
1°40' 10
1°20'
1°0' 1.9 10
20
40
60
80
100

E M B



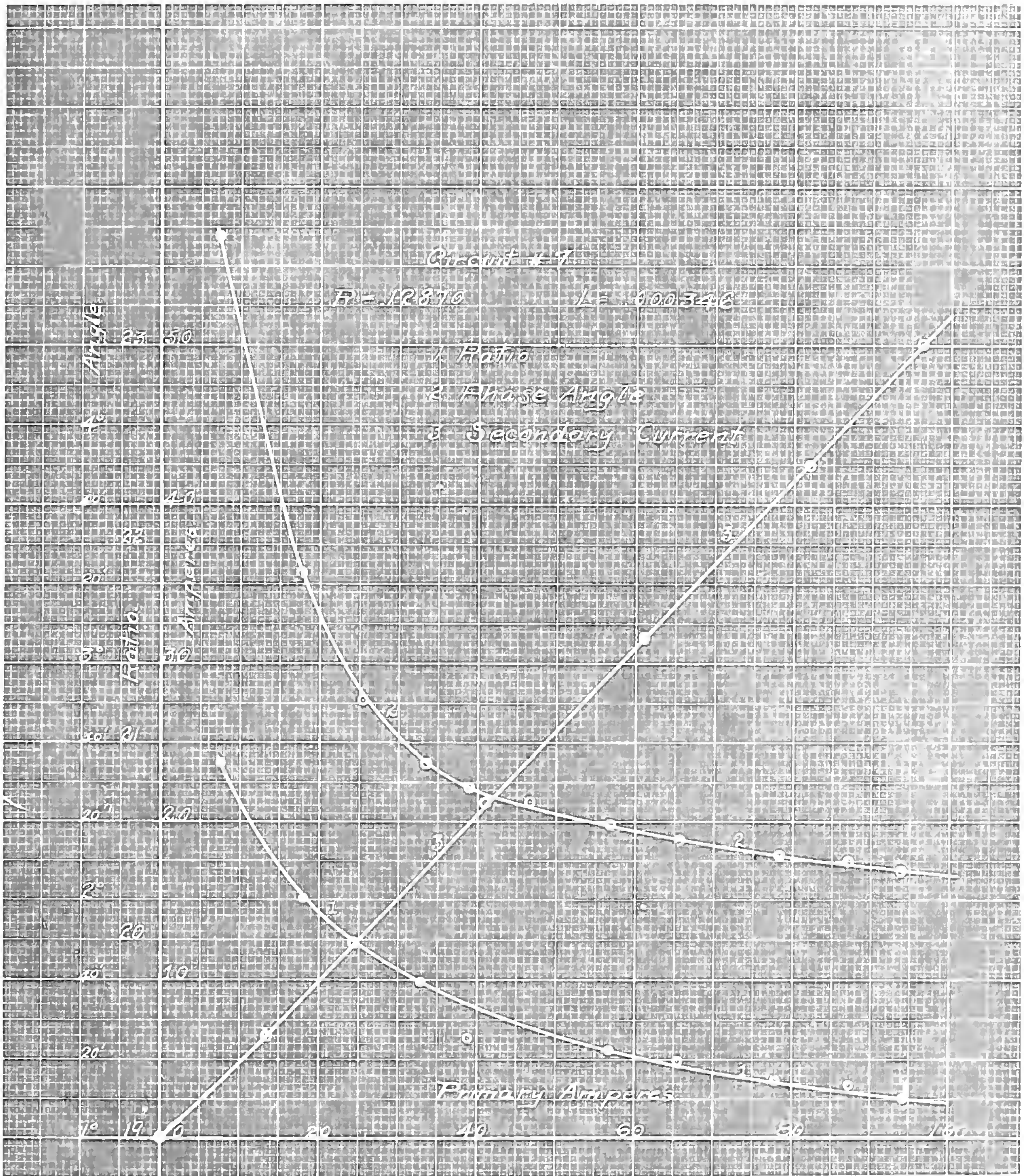
Circuit #4
R = .3546   L = .003586
1 Ratio
2 Phase angle
3 Secondary Current
Angle
Ratio
Secondary Amperes
Primary Amperes
0
20
40
60
80
100
10
20
30
40
50

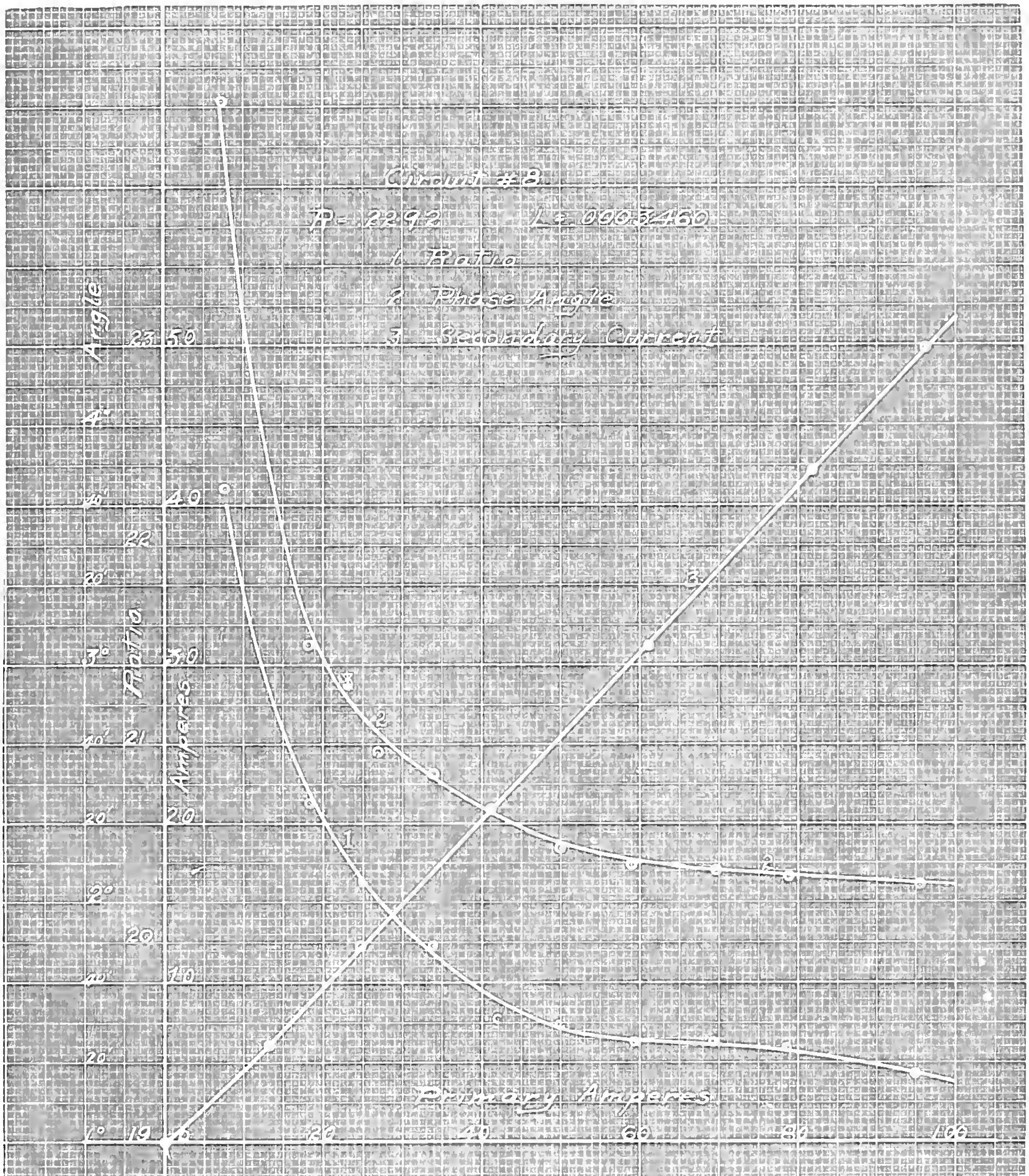

Circuit #5
R = .3546
L = .0056
1 Ratio
2 Phase angle
3 Secondary current
Angle
Ratio
Amperes
Primary Amperes
1°
2°
3°
4°
5°
19
20
2.1
22
23
1.0
2.0
3.0
4.0
5.0
20
40
60
80
100

E.M.B

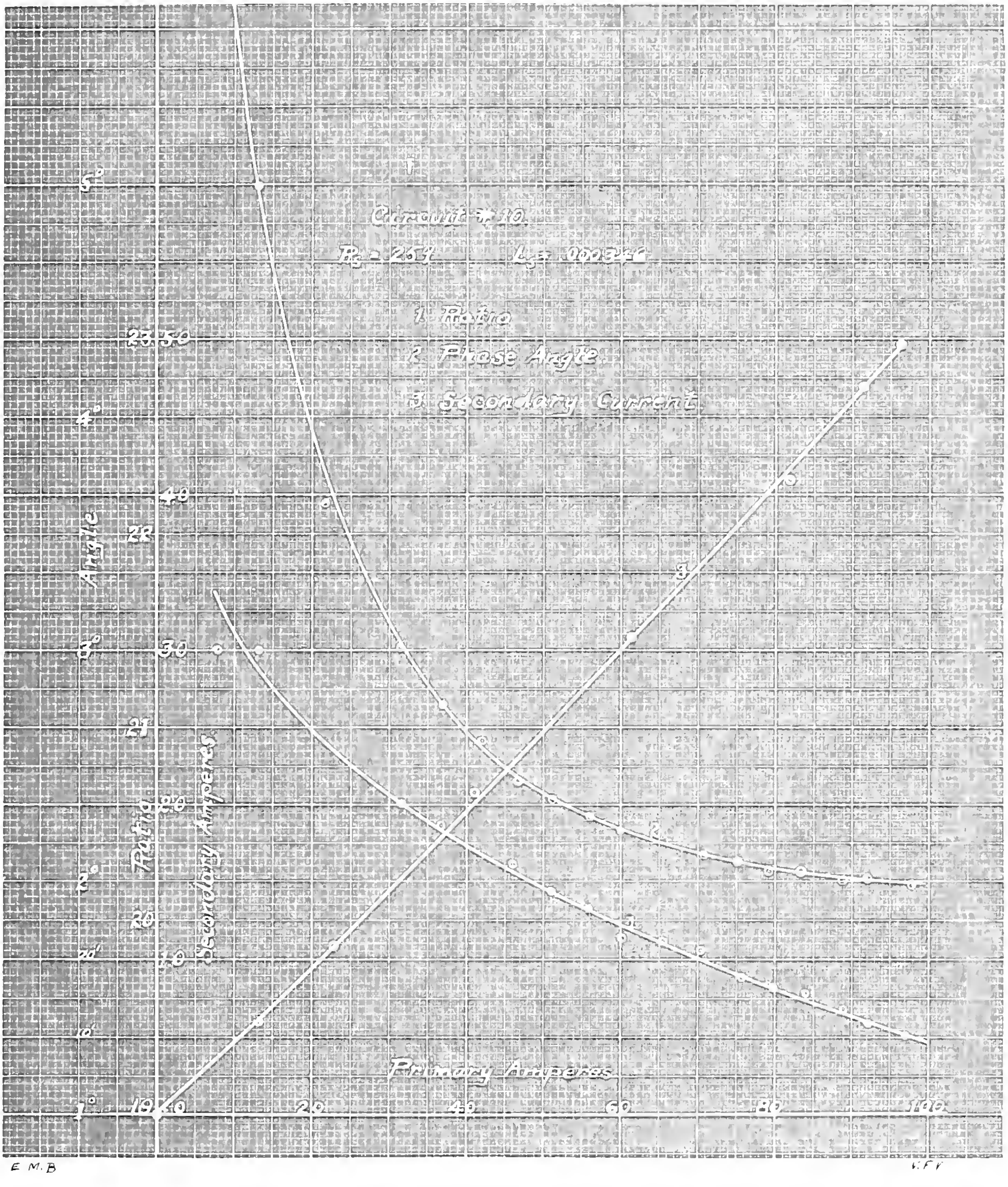

Circuit #6
R = 35460
L = .0228
1 Ratio
2 Phase Angle
3 Secondary Current
Angle
Ratio
Amperes
Primary Amperes
20
40
60
80
100

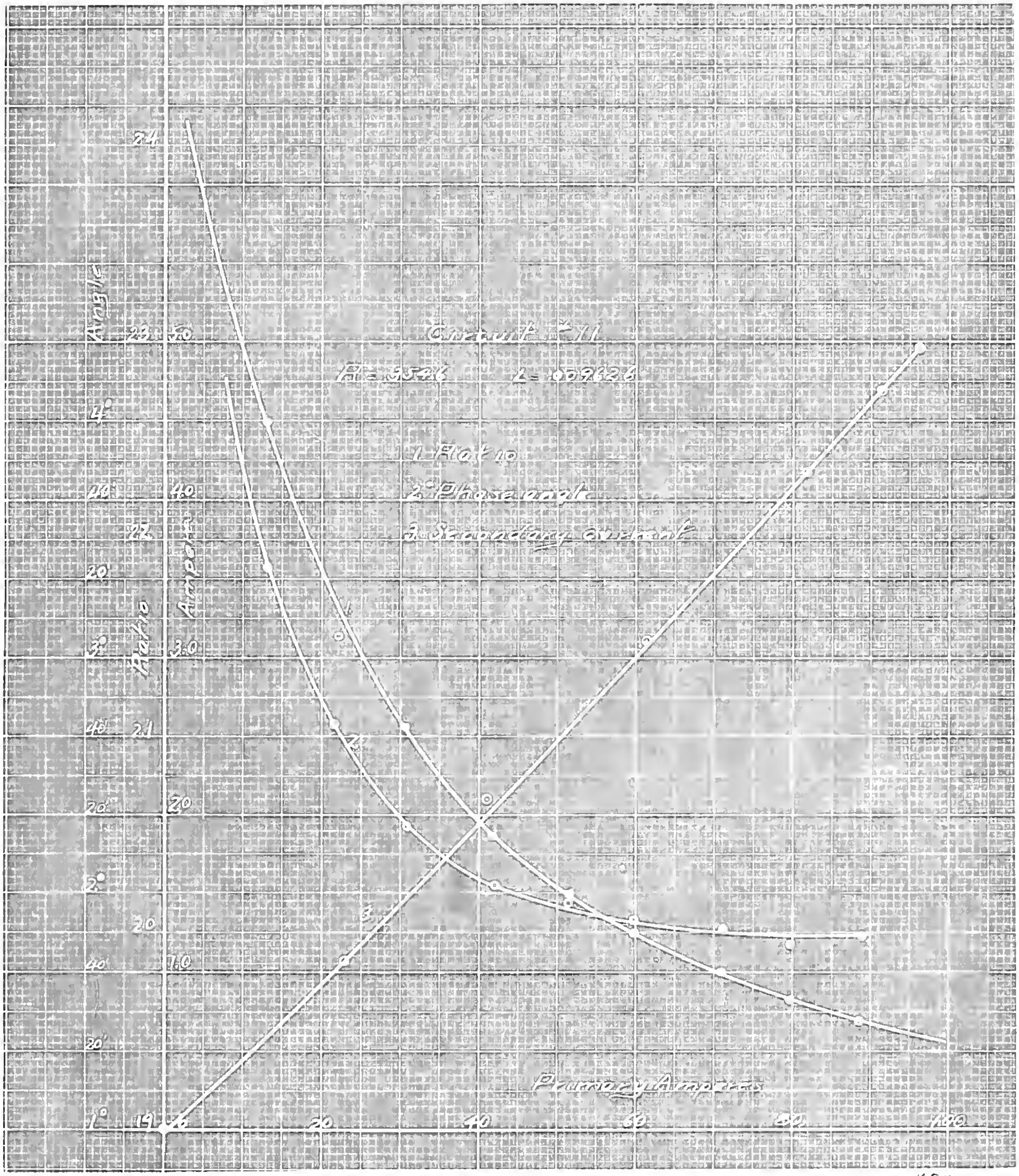
E.M.B


Circuit # 1
R = .12870
L = .000346
1 Ratio
2 Phase Angle
3 Secondary Current
Angle
Ratio
Amperes
Primary Amperes
E.M.B.


Circuit #8
R = .2292 L = .0003460
1 Ratio
2 Phase Angle
3 Secondary Current
Angle
Ratio
Amperes
Primary Amperes
23
22
21
20
19
50
40
30
20
10
4°
3°
2°
1°
20
40
60
80
100

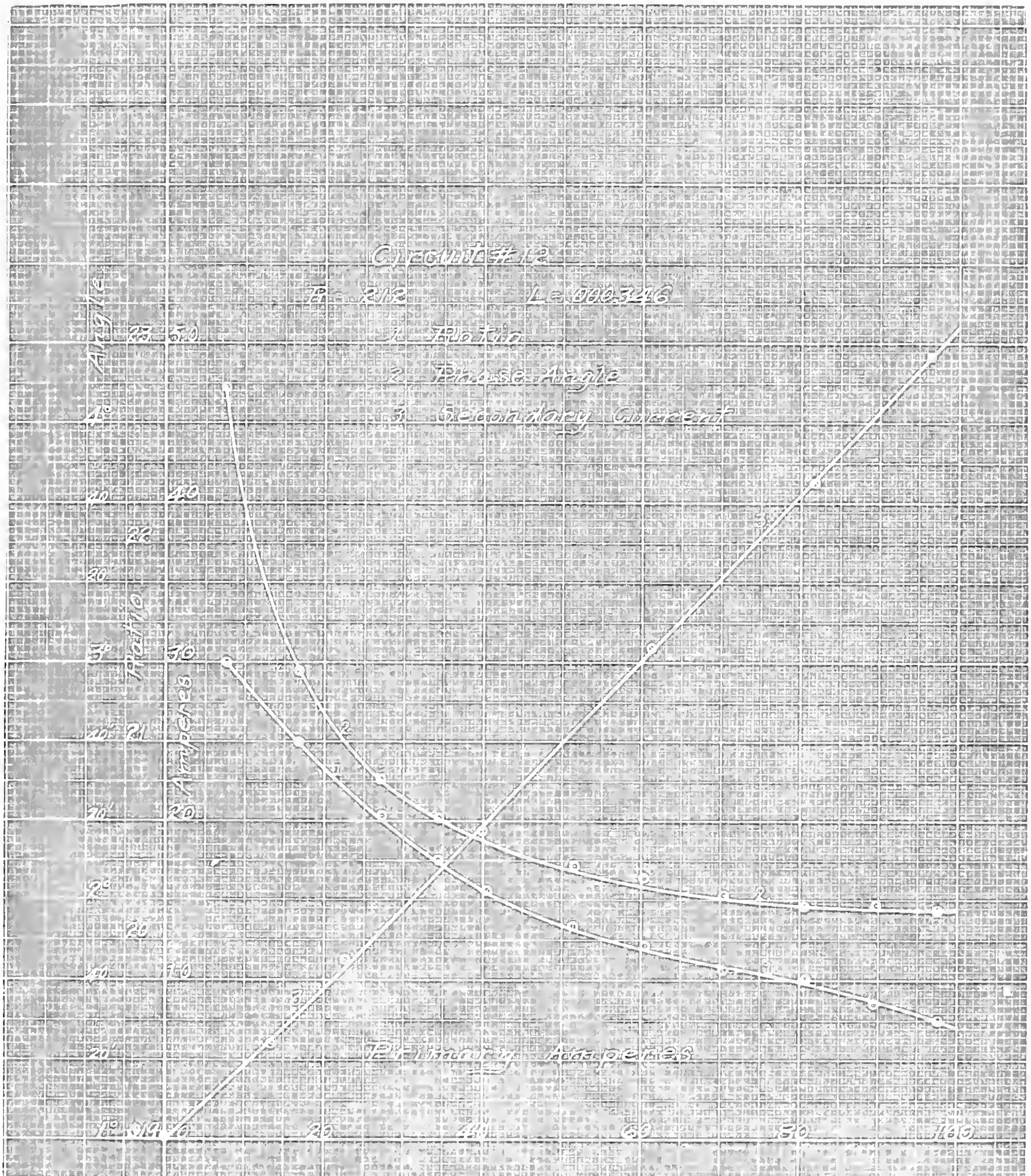
E.M.B V.F.V


Circuit # 10.
Rs = .264
Ls =
1 Ratio
2 Phase Angle
3 Secondary Current
Angle
Ratio
Secondary Amperes
Primary Amperes
5°
4°
3°
2°
1°
50
40
30
10
20
40
60
80
100
23
22
21
20
E.M.B
V.F.V

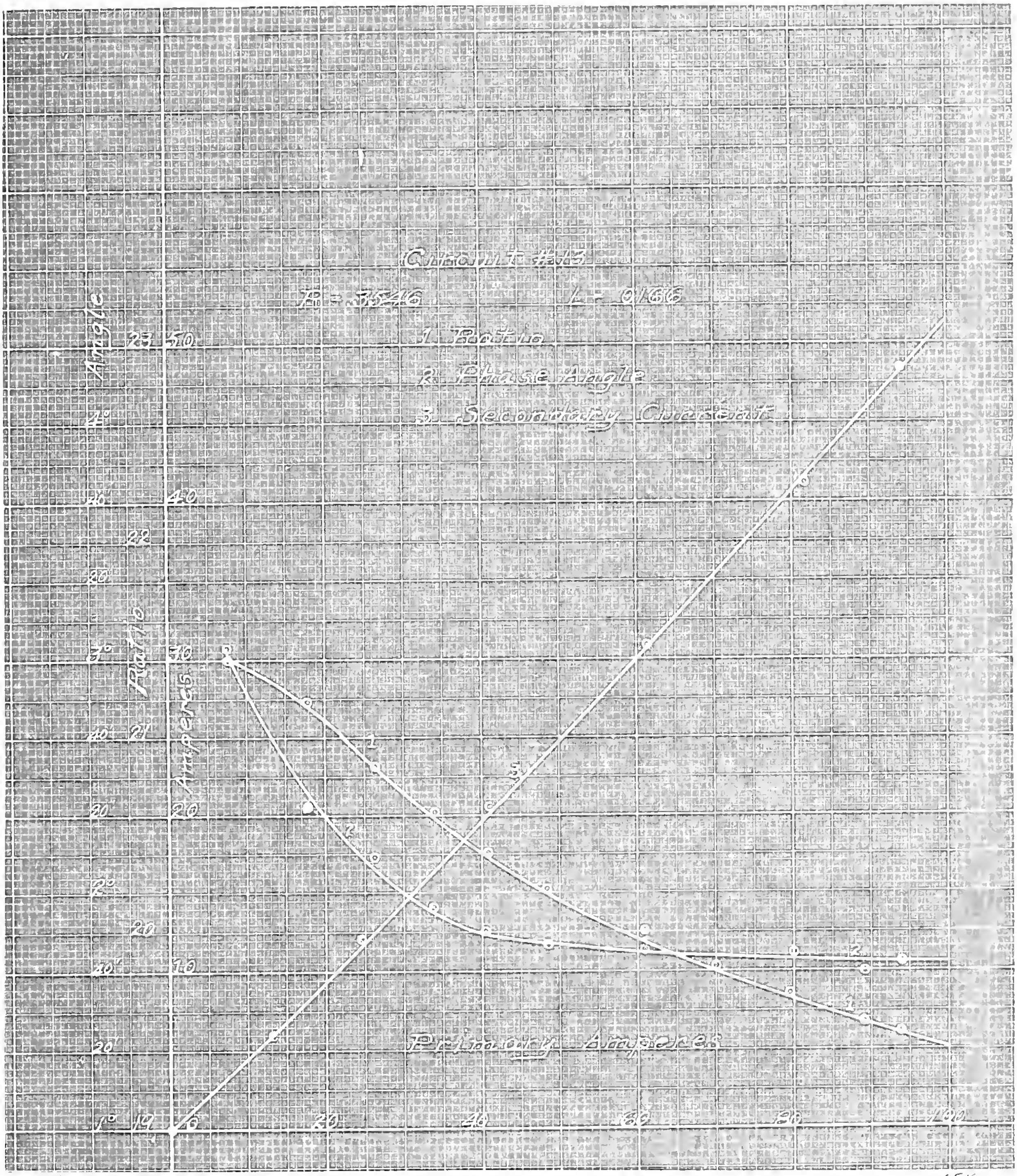

Circuit 11
R = .9546   L = .009326
1. Ratio
2. Phase angle
3. Secondary current
Angle
Ratio
Amperes
Primary Amperes
20
40
60
80
100
1.0
2.0
3.0
4.0
5.0

E.M.B

VFV

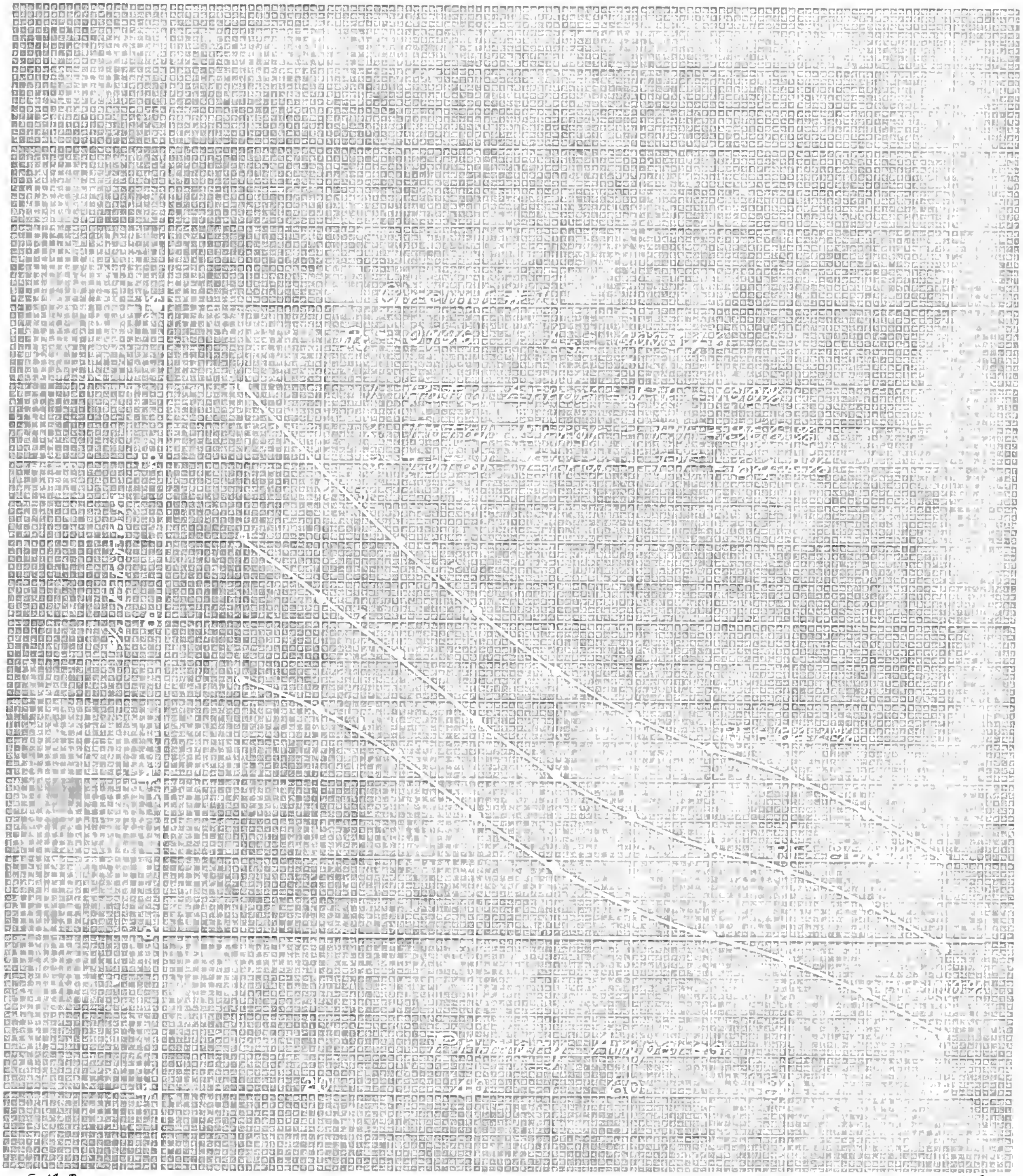

Circuit #12
R = R12
L = 000.346
1 Ratio
2 Phase Angle
3 Secondary Current
Angle
Ratio
Amperes
Primary Amperes
20
40
60
80
100

E M B

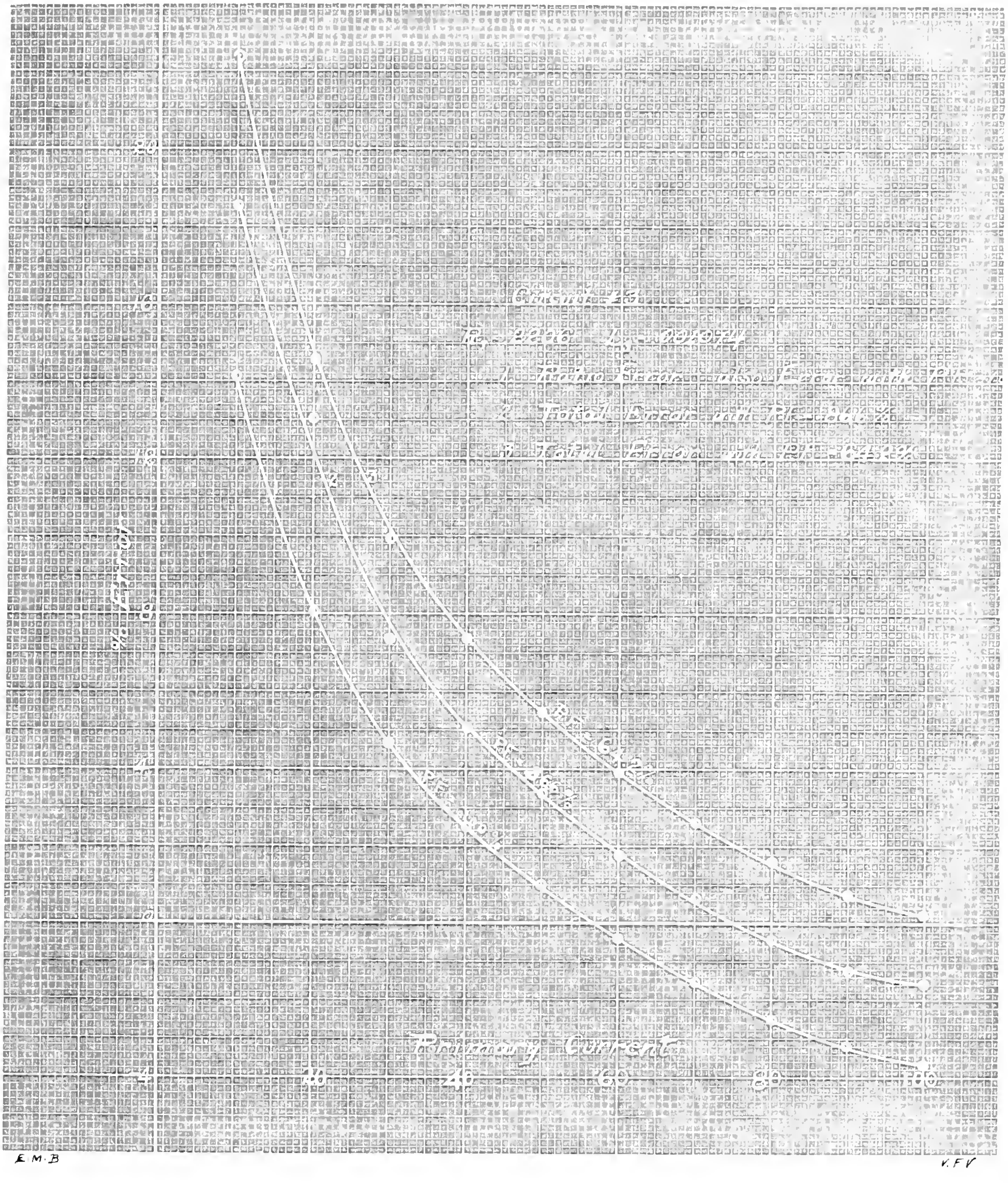

Circuit #13
R = .3546
L = .0166
1. Ratio
2. Phase Angle
3. Secondary Current
Angle
Ratio
Amperes
Primary Amperes

E.M.B

V.F.V

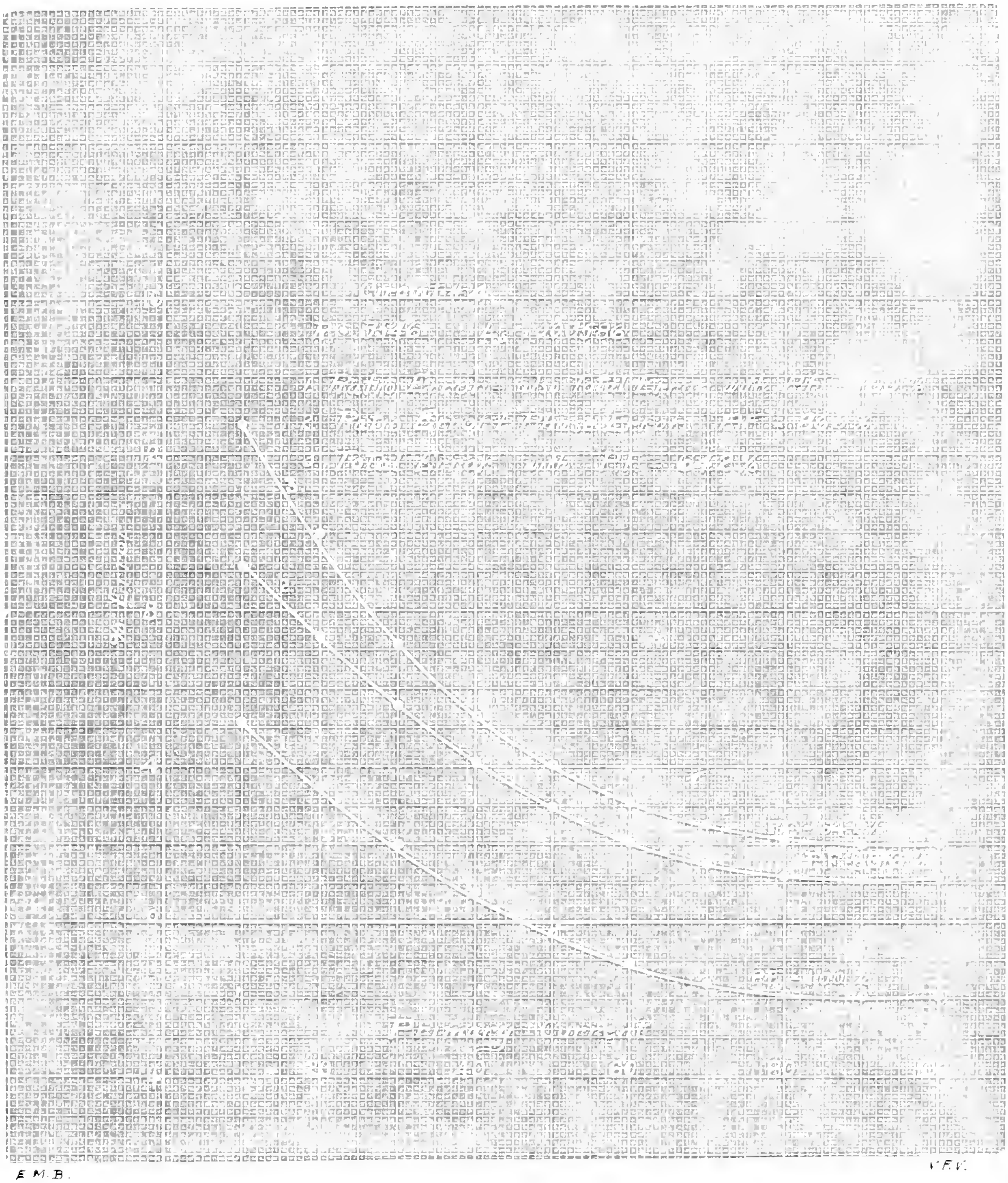


E.M.B V.F.V.



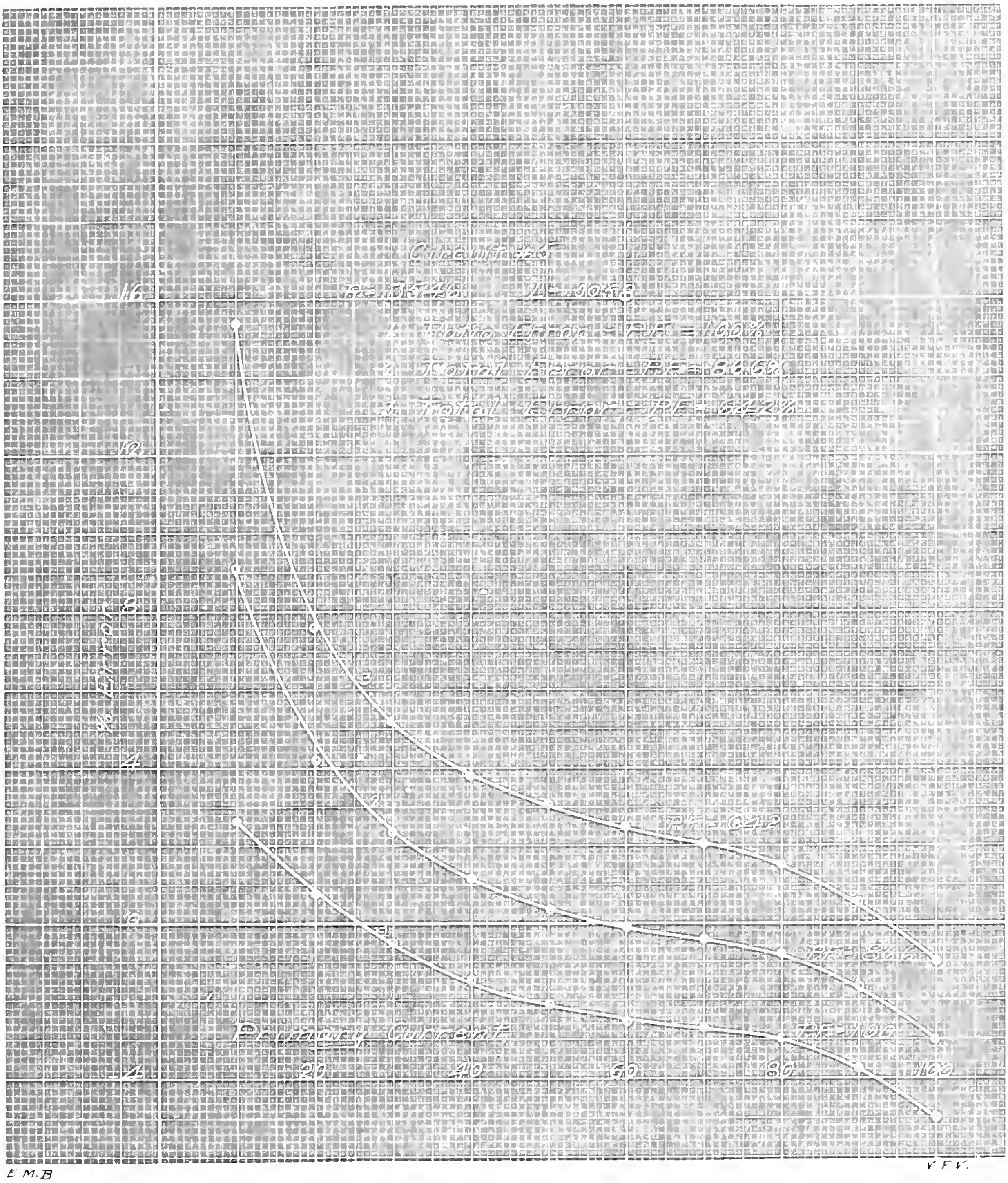
E.M.B

V.F.V

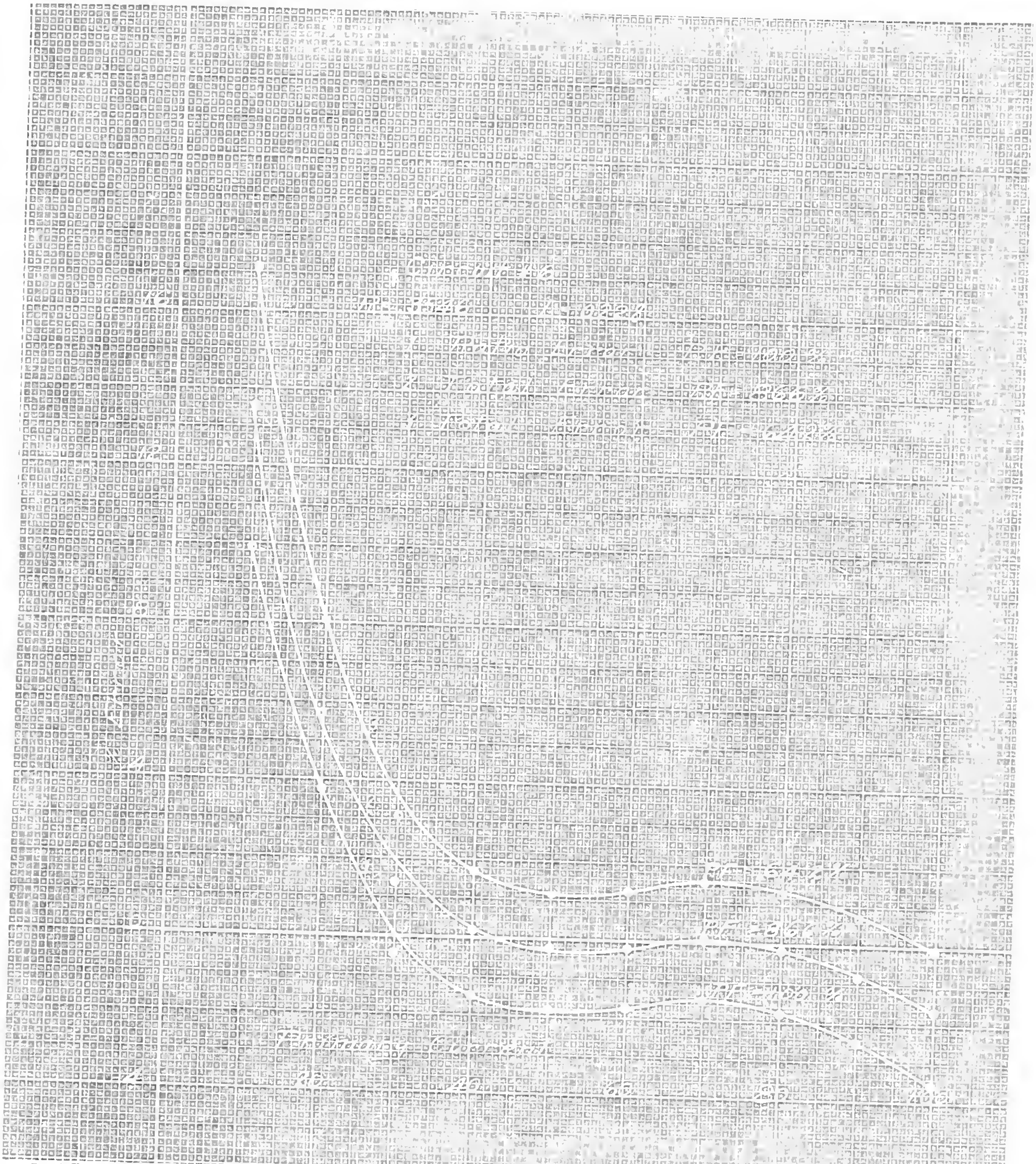


E. M. B.

V. F. V.

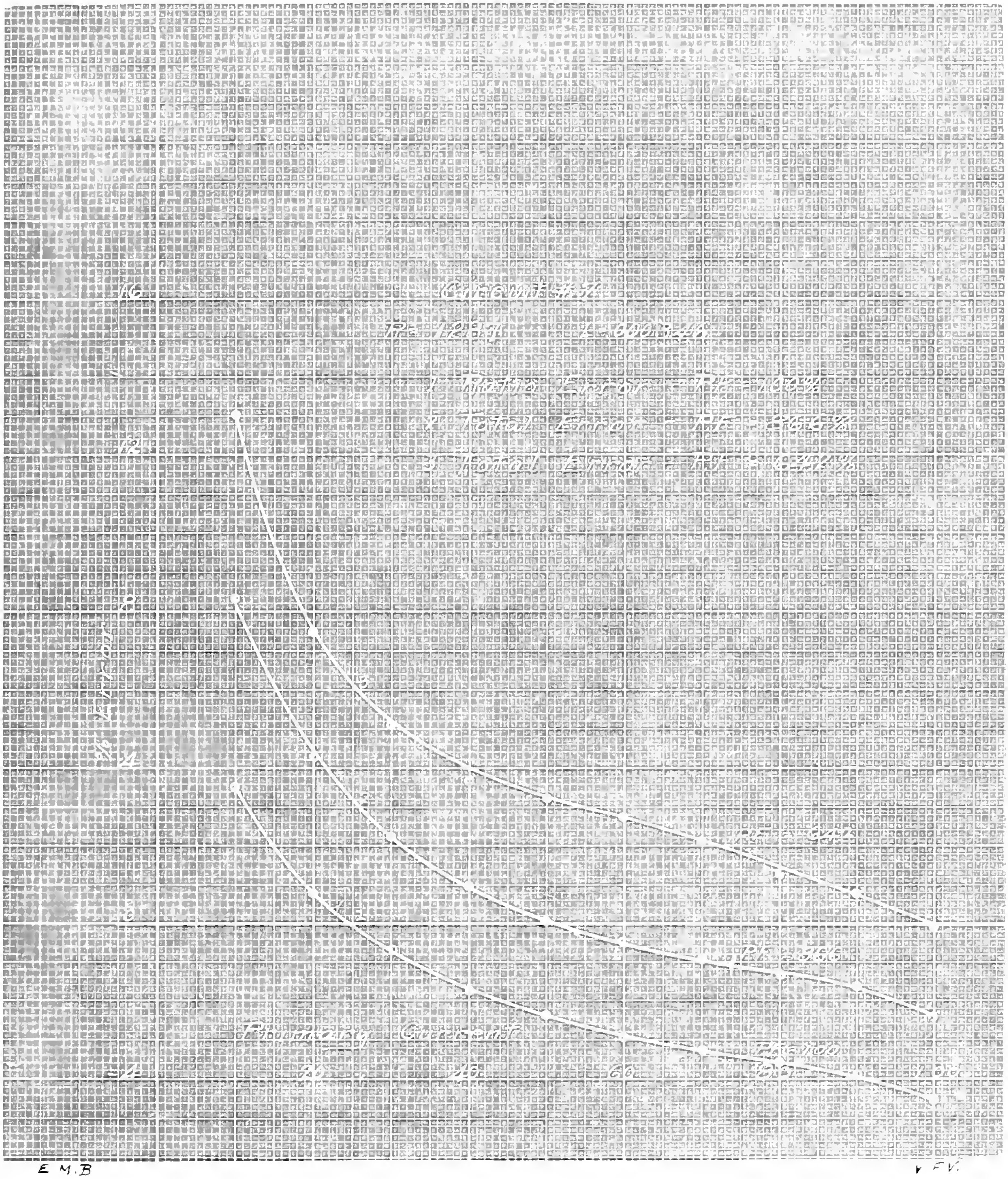

Circuit #5
1. Ratio Error - P.F. = 100%
2. Total Error - P.F. = 86.6%
3. Total Error - P.F. = 64.2%
16
12
8
4
0
-4
% Error
Primary Current
20
40
60
80
100
PF=64.2
PF=86.6
PF=100

E.M.B.   V.F.V.

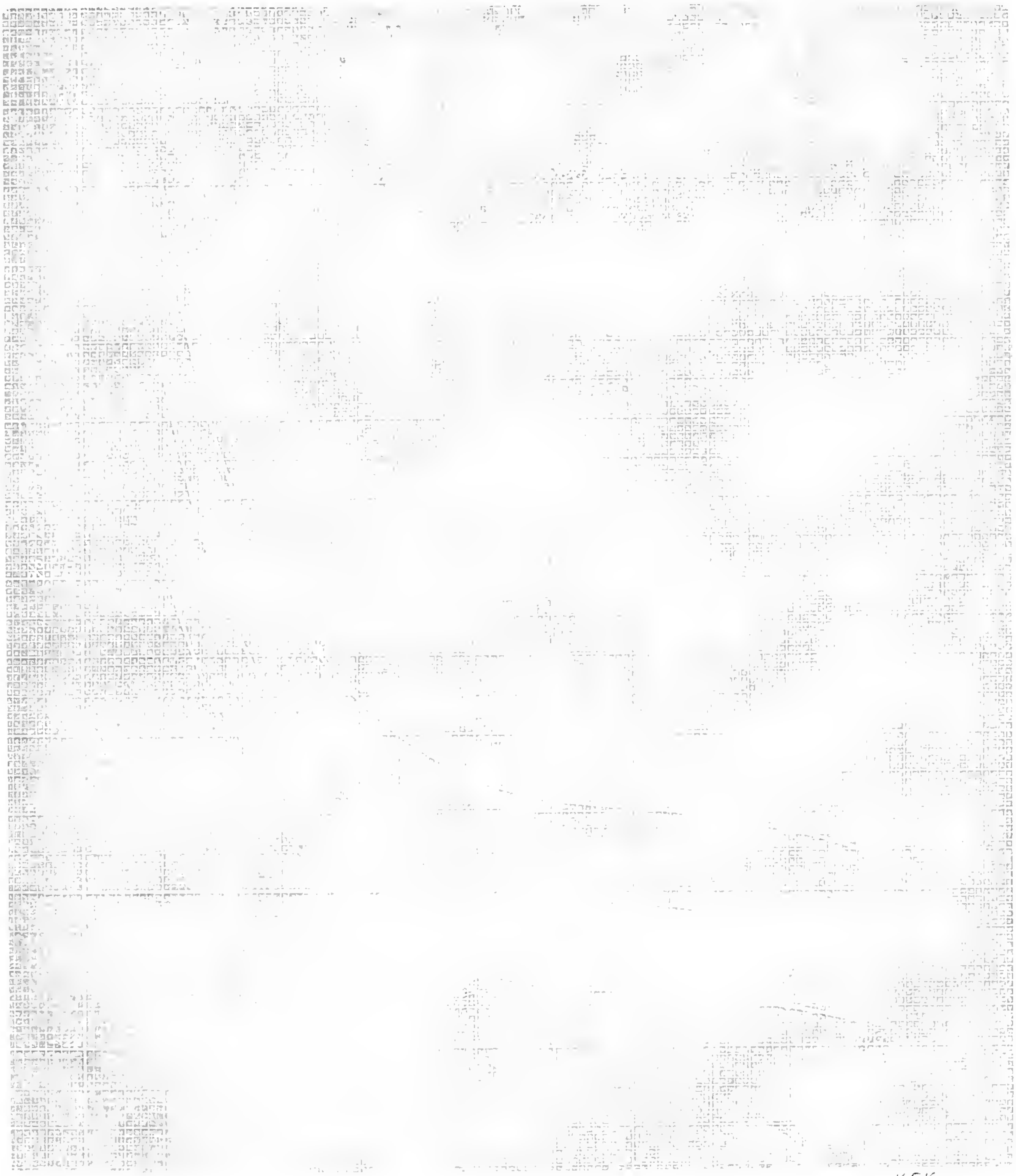


E.M.B

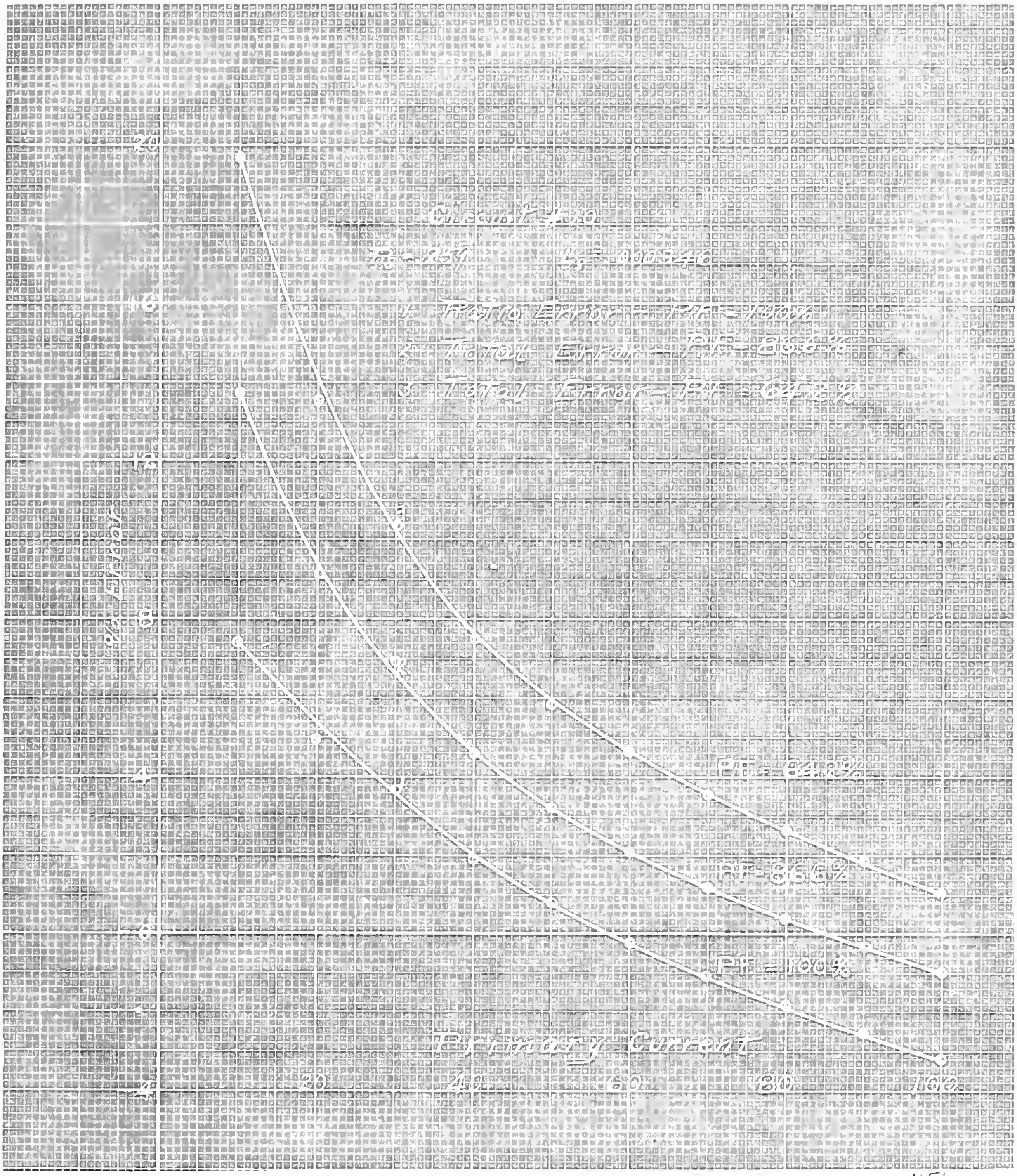
VFV


16
12
8
4
1. Ratio Error
2. Total Error
3. Total Error
Primary Current

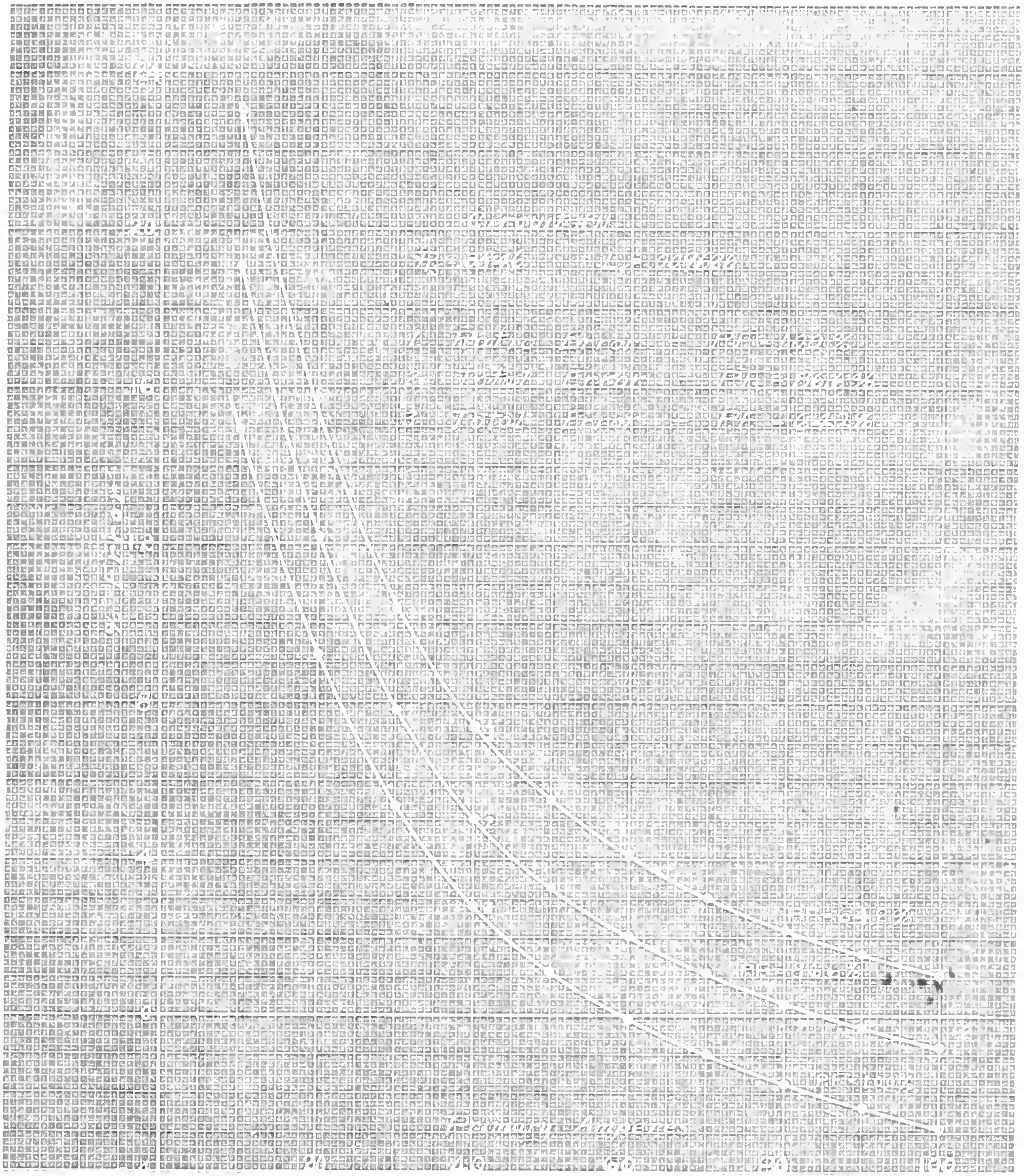
E.M.B. F.V.



E.M.B. V.F.V.

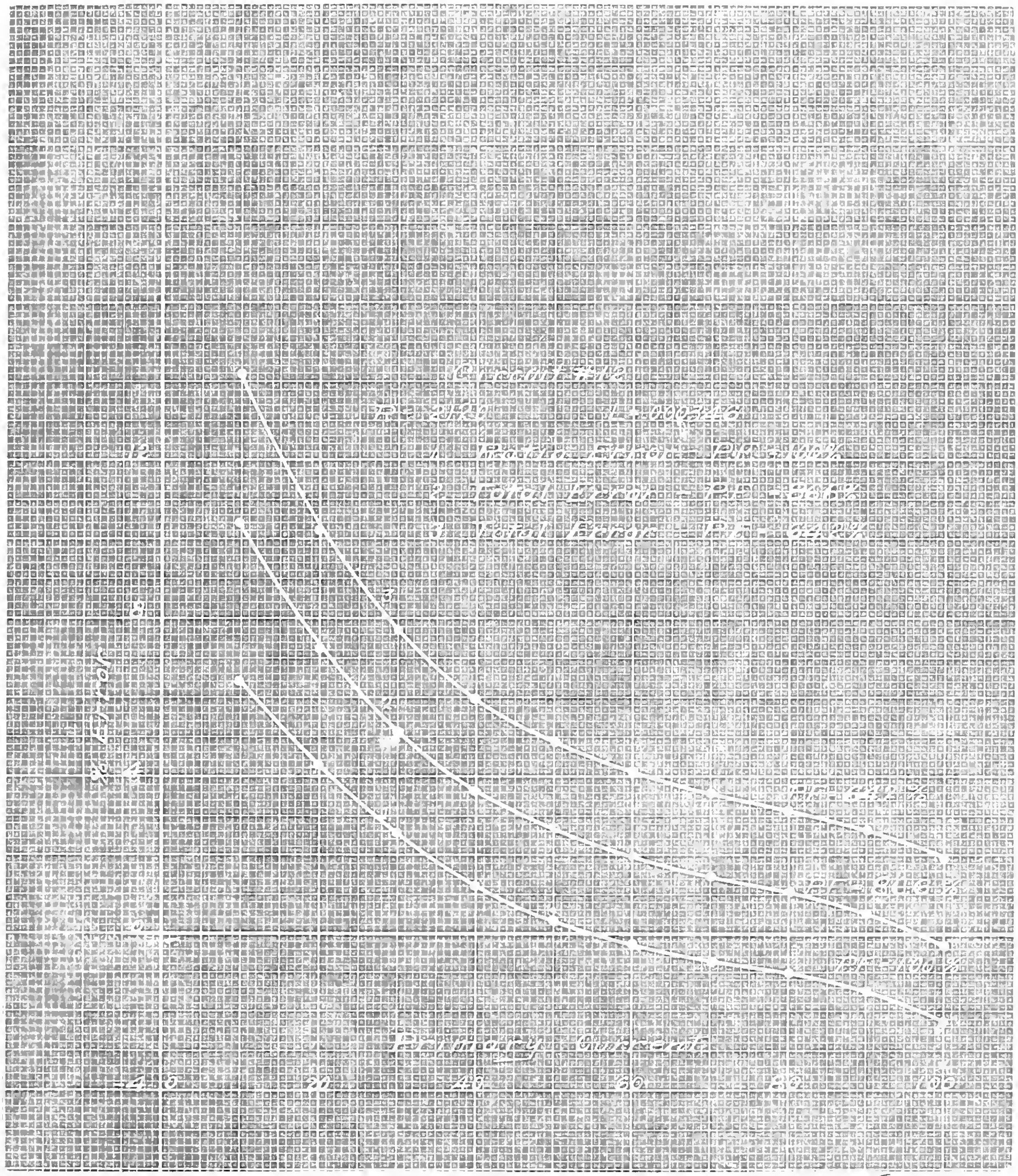

1. Ratio Error - PF = 100%
2. Total Error - PF = 86.6%
3. Total Error - PF = 64.2%
PF = 64.2%
PF = 86.6%
PF = 100%
% Error
Primary Current
20
40
60
80
100

E.M.B. V.F.V.



E.M.B.

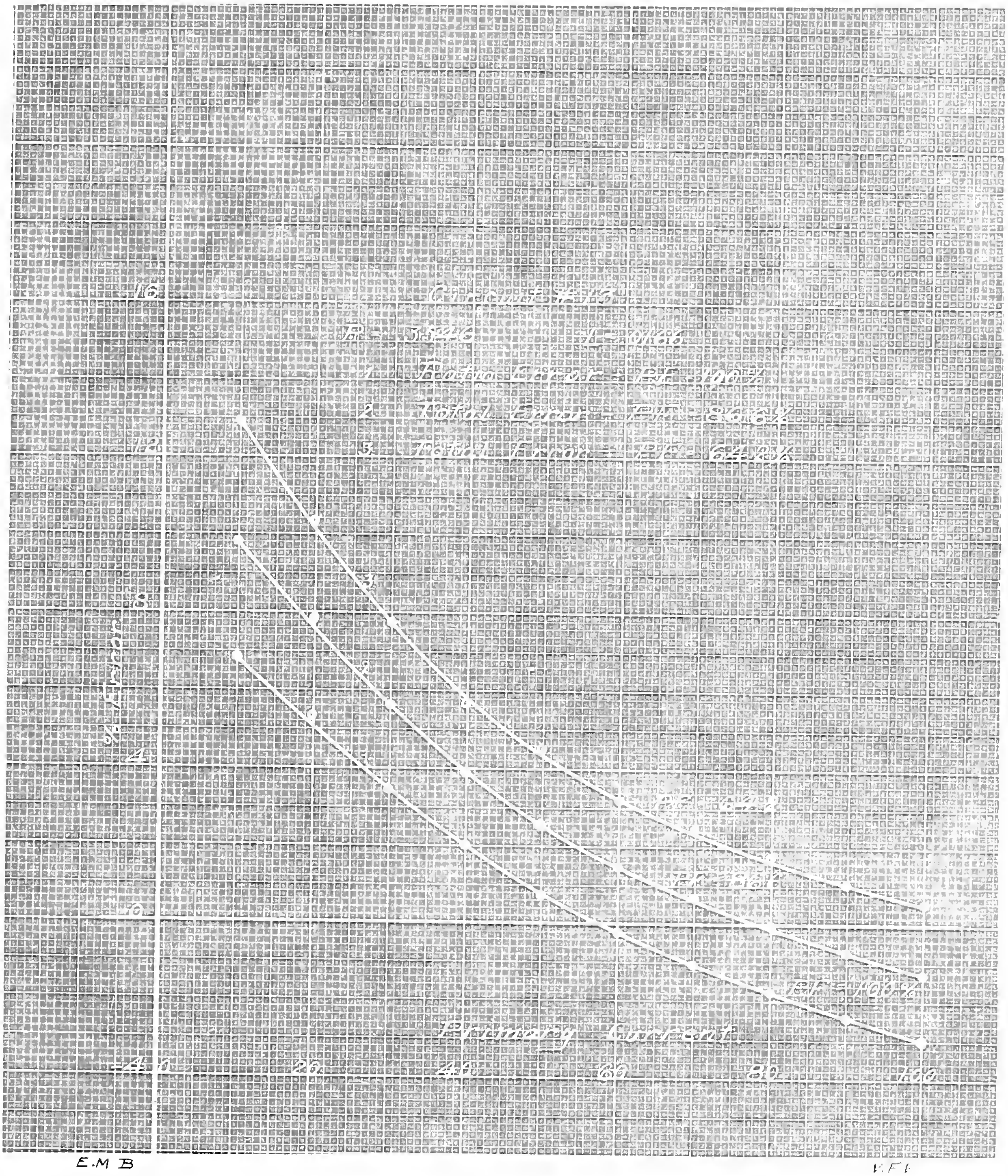
V.F.V.



Circuit #12
1 Ratio Error
2 Total Error
3 Total Error
P.F. = 100%
% Error
12
8
4
0
-4
0
20
40
60
80
100
Primary Current

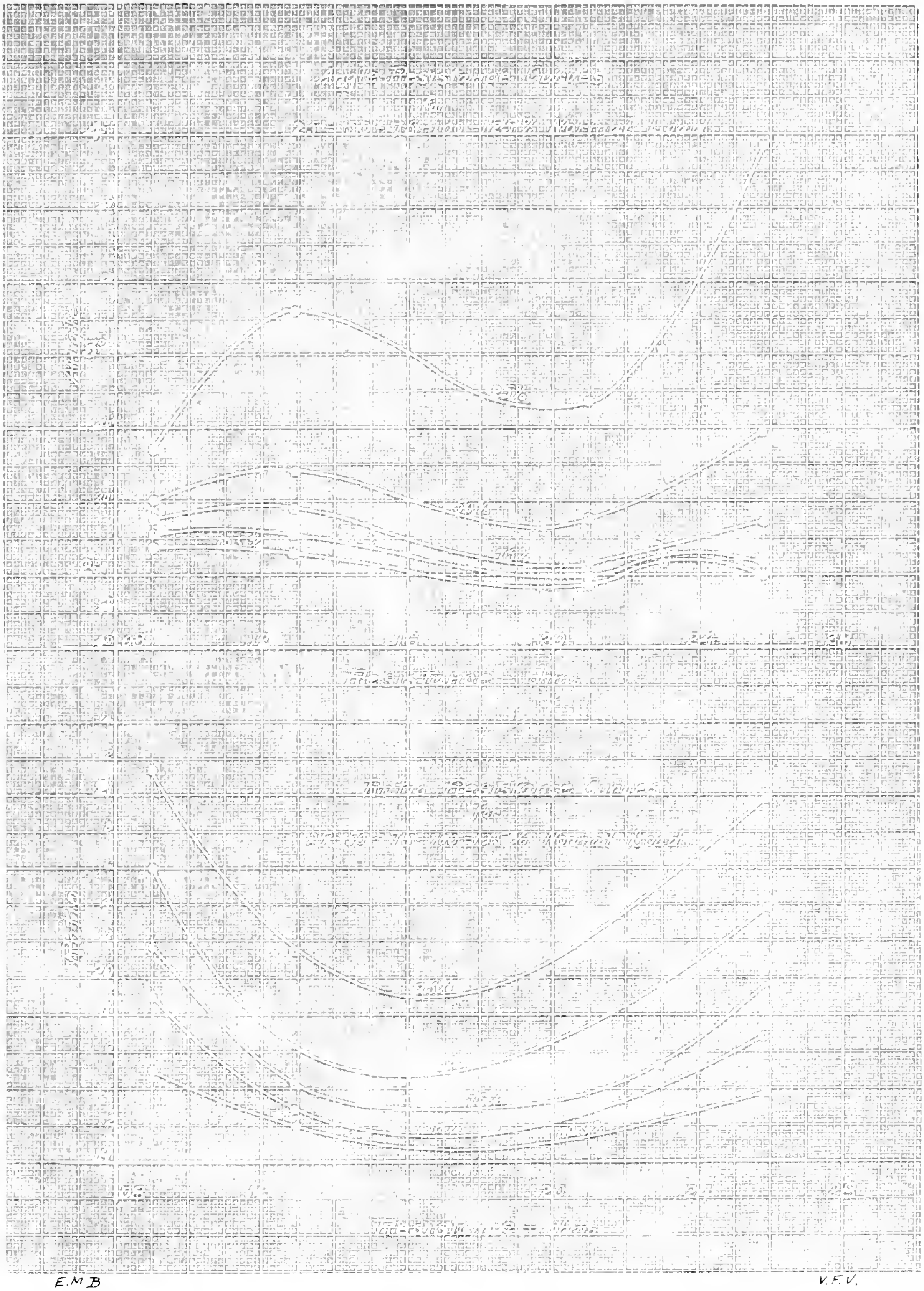
E M B

L.F.V.

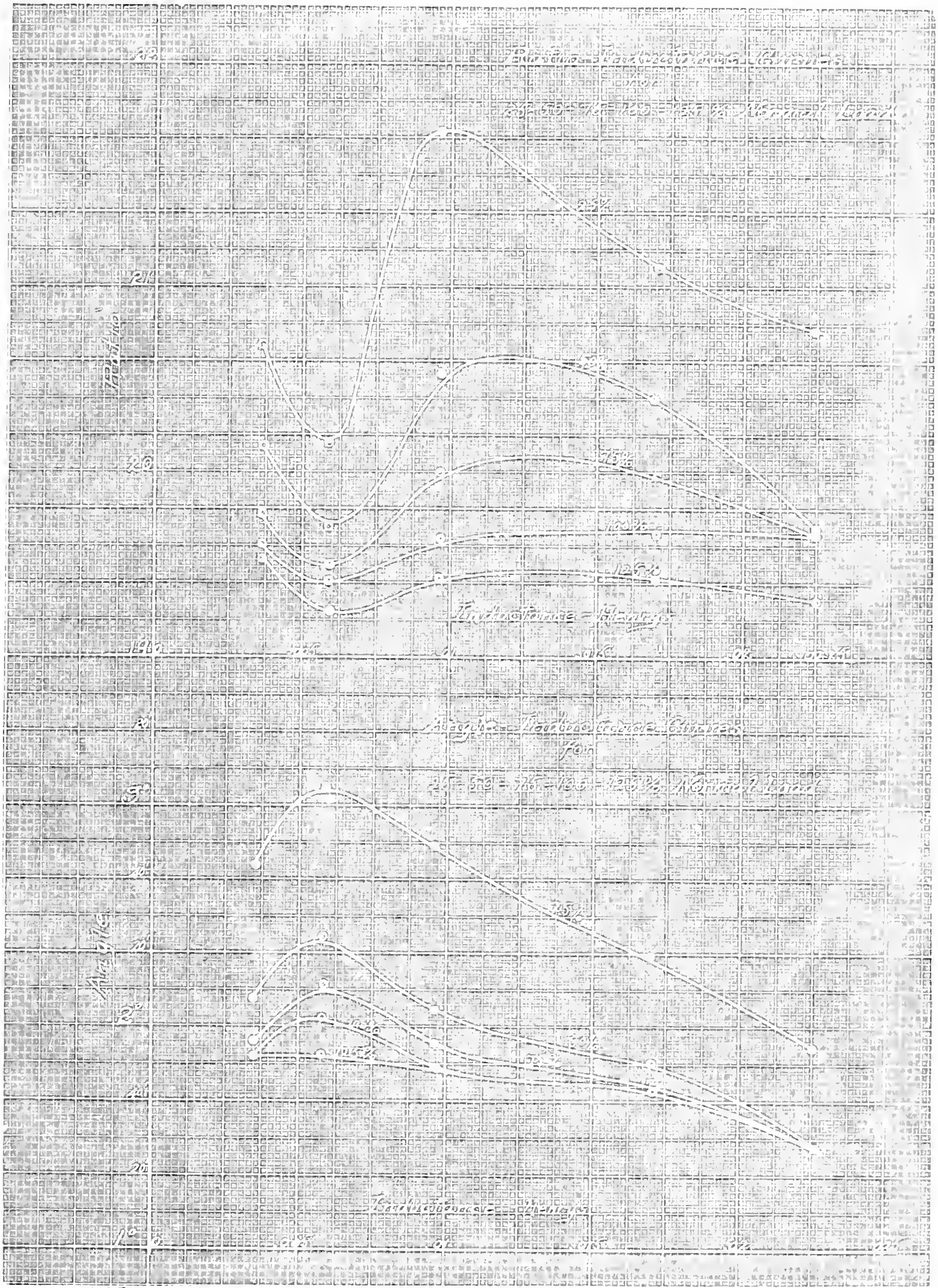

Circuit #13
R = 3.546
L = .0166
1 Ratio Error - P.F. 100%
2 Total Error - P.F. 86.6%
3 Total Error - P.F.
% Error
16
12
8
4
0
-4
0
20
40
60
80
100
Primary Current
P.F. 100%

E.M.B

V.F.I

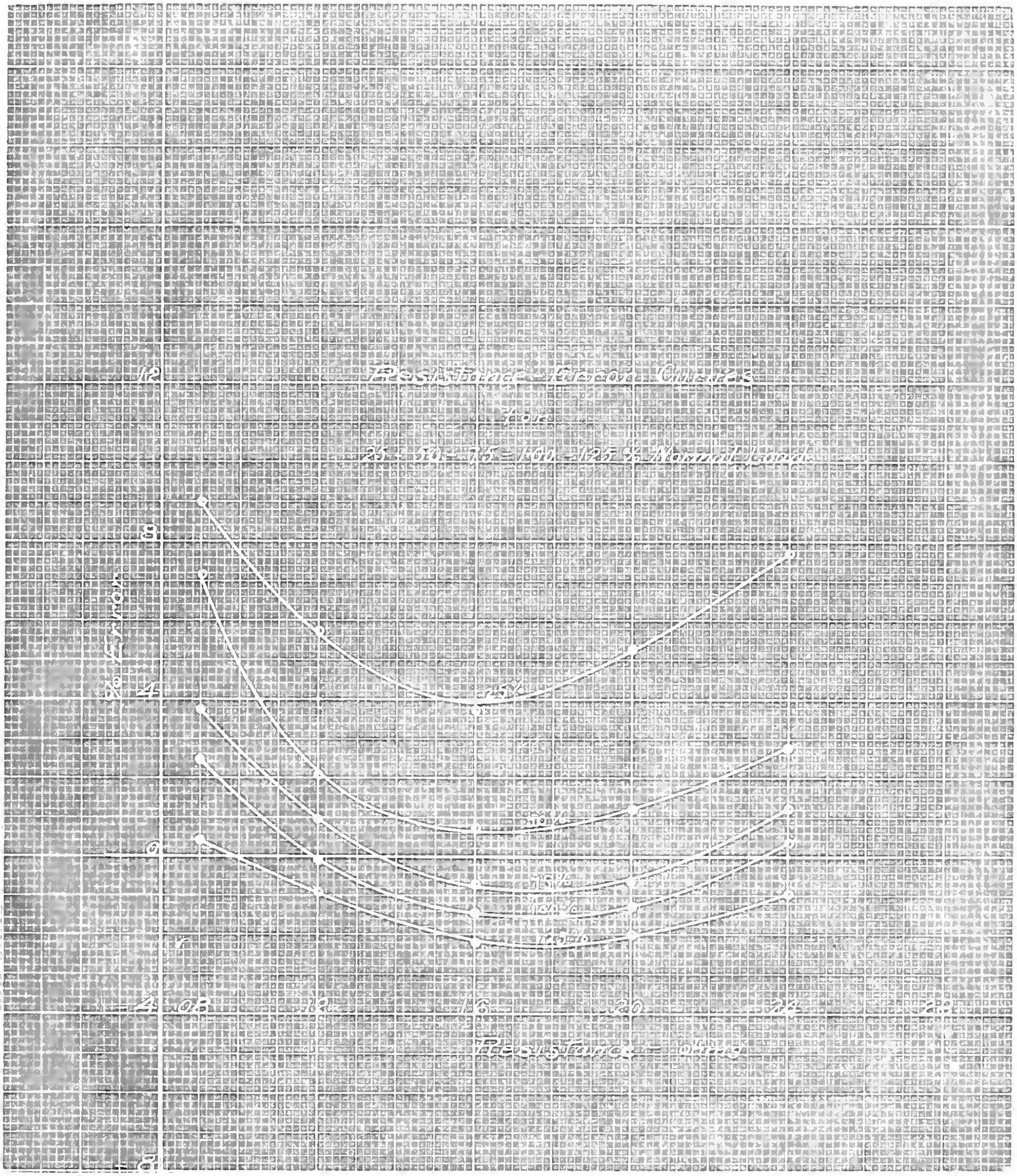


E.M.B V.F.V.



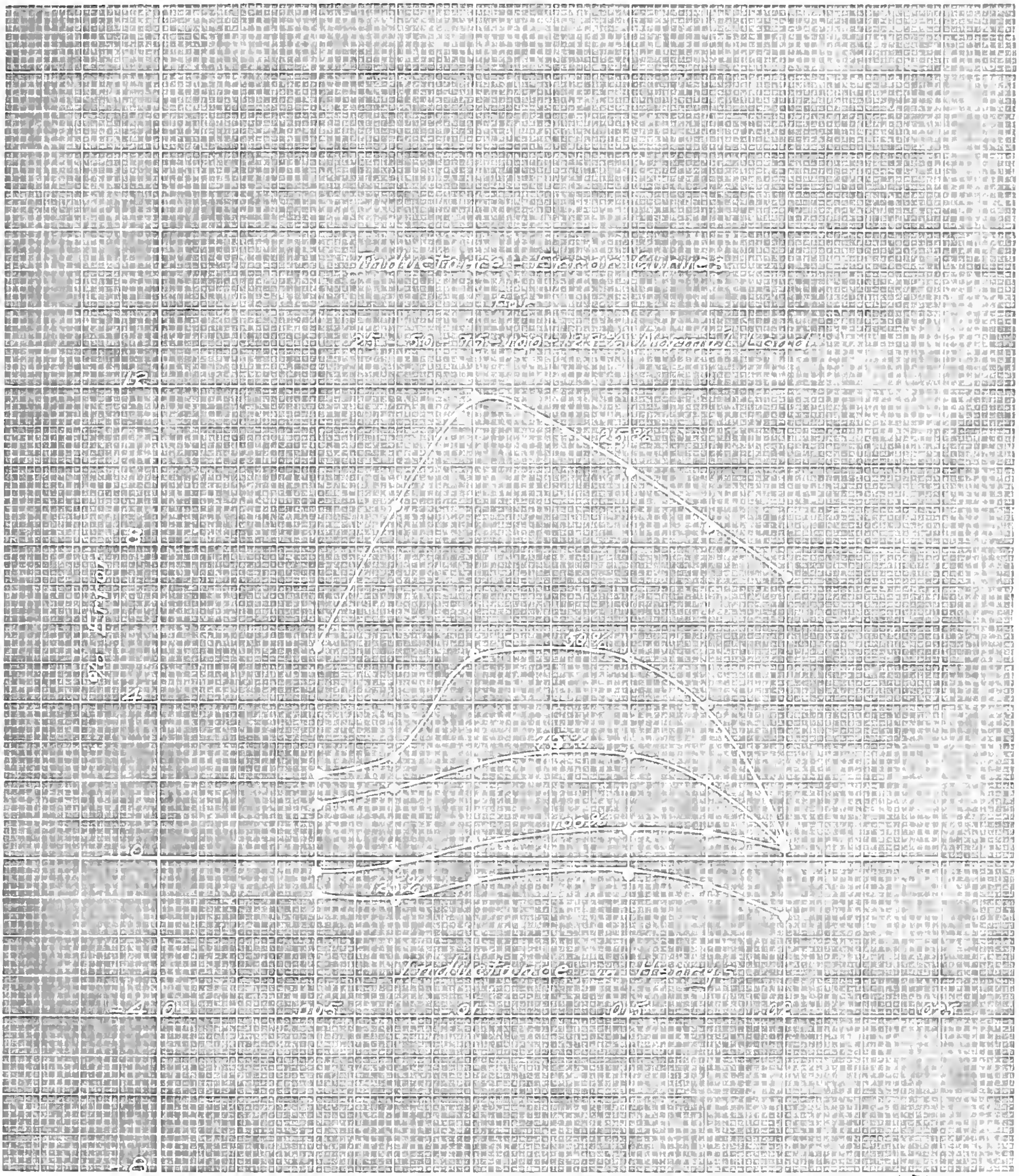
E.M.B.

V.F.V.



Resistance – Error Curves
for
25 – 50 – 75 – 100 – 125 % Normal Load
% Error
Resistance – Ohms
12
8
4
0
4
8
0.8
1.2
1.6
2.0
2.4
2.8
25%
50%
75%
100%
125%

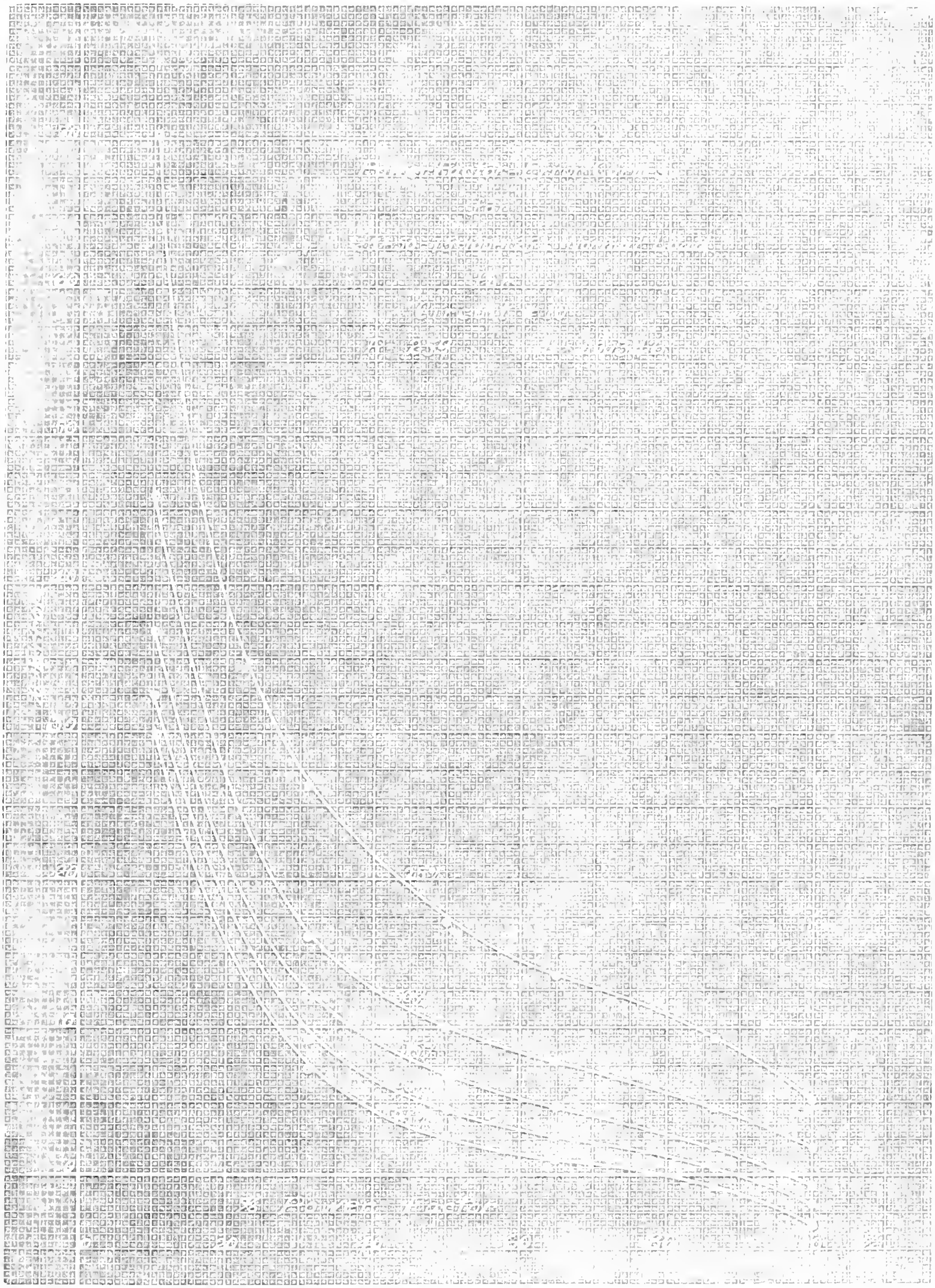
E. M. B. V. F. L.



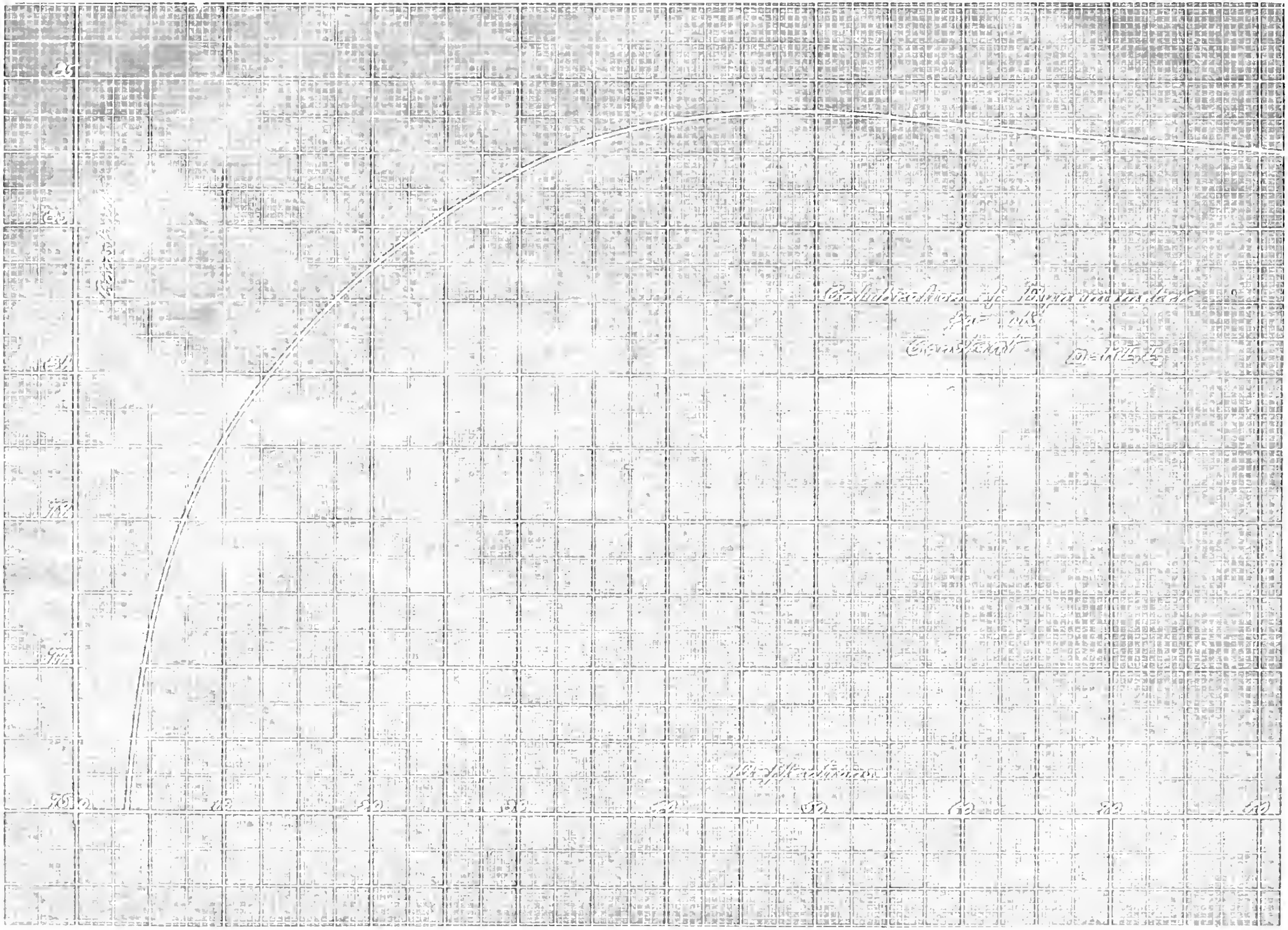
Inductance - Error Curves
For
25 - 50 - 75 - 100 - 125 % Normal Load
12
25 %
8
% Error
50 %
4
75 %
100 %
1.0
125 %
Inductance in Henrys
.005
.01
.015
.02
.025

E.M.B

V.F.I



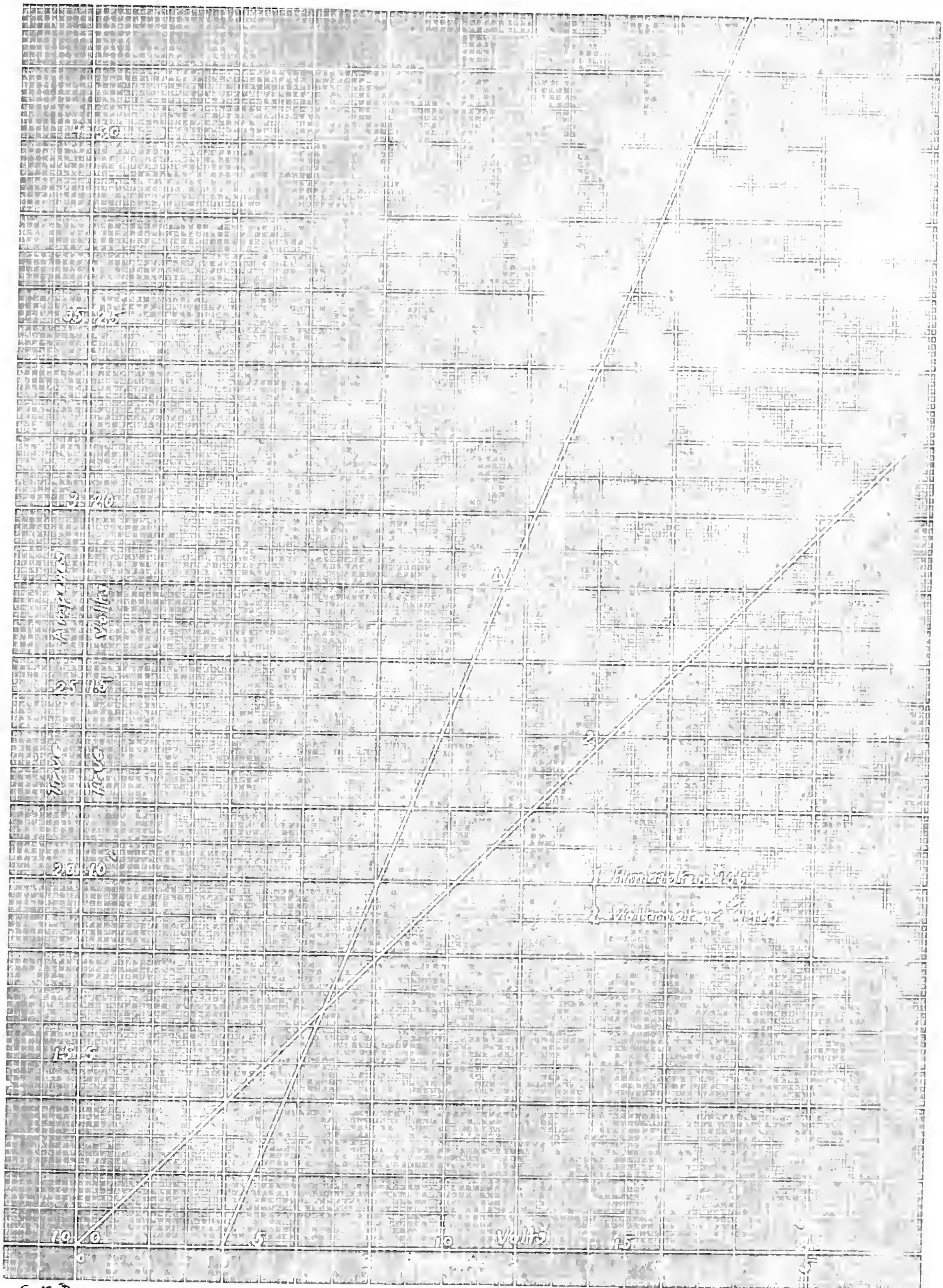
EMB V.F.V.



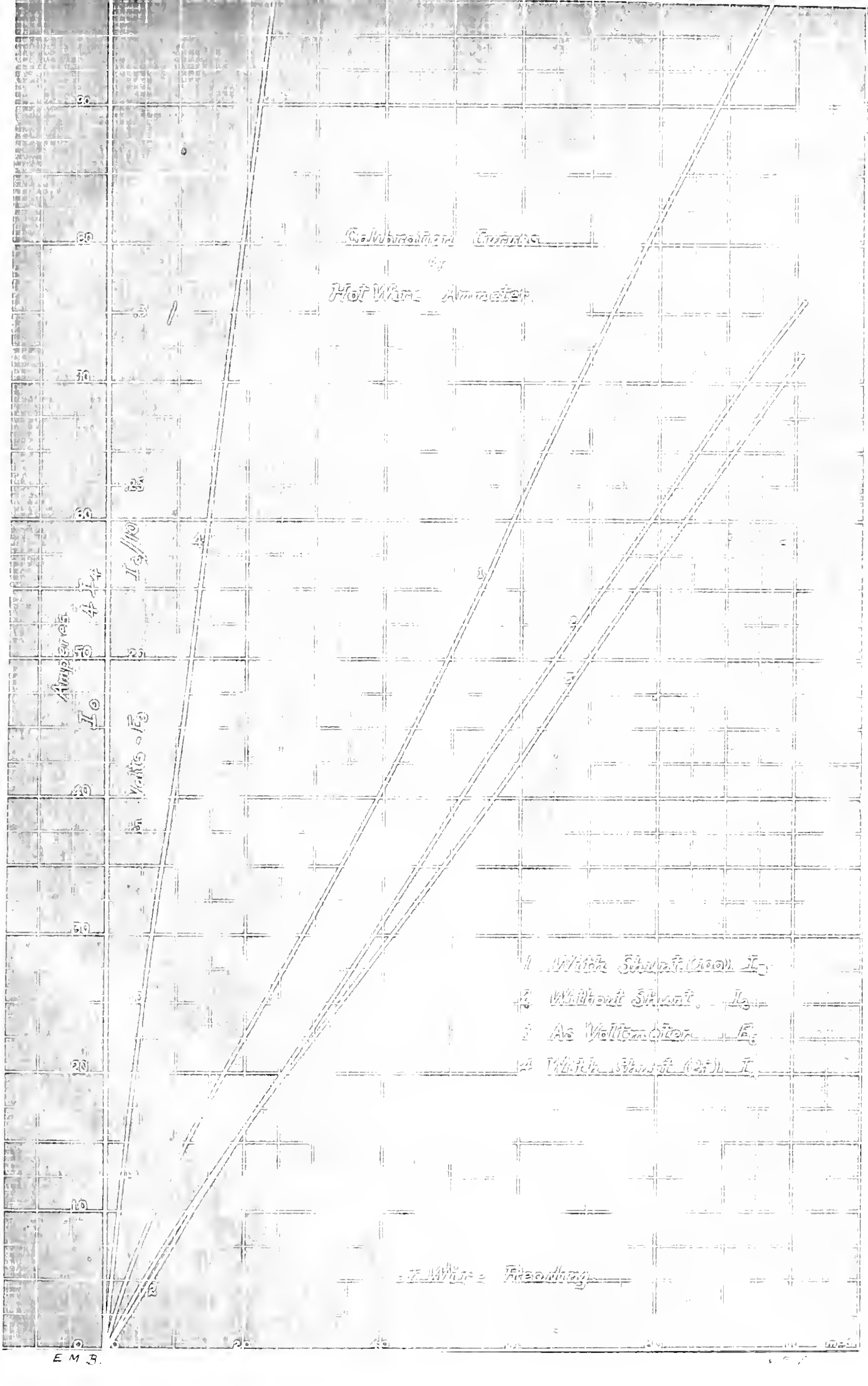
E.M.B

V.F.I

E.M.B.



E M B.



Calibration Curves
of
Hot Wire Ammeter
1 With Shunt (100) I_o
2 Without Shunt I_g
3 As Voltmeter E_g
4 With Shunt (25) I_4
Amperes I_o $4 I_4$
Volts - E_g
$I_g/10$
Hot Wire Reading
E M B.